Developing Protocols to Support Collaborative Teacher Reflection and Professional Learning for Science Argument Writing

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Introduction

Focusing on scientific practices such as argumentation is a significant shift for secondary school science instruction away from the traditional prioritization of content. The successful integration of new science standards like the Next Generation Science Standards (NGSS) into classroom practice depends not only on their acceptance, but also on opportunities for teachers to explore how the standards translate into their classroom instruction. Professional learning communities have shown promise as mechanisms for changing teacher practice and in turn improving student learning (Vescio, Ross, & Adams, 2008). These communities are defined by groups of teachers who work together to assess their progress, make corrections, and hold themselves accountable for achieving a shared goal (McLaughlin & Talbert, 2010). In their article calling for design-based research studies to support the broad and deep implementation of NGSS, however, Penuel and Fishman (2012) noted the dearth of research on how promising strategies such as professional learning communities guided by discussion protocols could support the implementation of the new science standards.

Responding to this dearth, this paper describes the development of a suite of teacher reflection protocols that were designed to structure generative conversations among teachers about instruction in support of students' written scientific arguments. Guided by the principles of design-based implementation research, we engaged in multiple cycles of design, implementation, and refinement to develop three distinct protocols, each of which is geared to a different stage of an instructional cycle: lesson planning, assignment refinement, and reflection on student work. All the protocols are designed to focus teachers' discussions on specific features of scientific argument prompts and instructional supports for students to write an argument. By explicitly grounding the research in components of the NGSS Science and Engineering Practices, the suite of protocols is designed to support teachers with the complex process of developing students' emergent science argument writing practice.

Rationale

As evidenced by its inclusion in national and state standards, argumentation is increasingly a prioritized practice in science education (National Research Council, 2011). Argumentation serves as a "core discursive activity" for scientists to construct knowledge and resolve controversies (Osborne, Erduran, & Simon, 2004, p. 3). A growing body of research points to the idea that students must practice arguing from evidence in science and constructing and justifying knowledge claims in order to comprehend the socially constructed nature of scientific knowledge instead of perceiving science as a collection of positivistic, static facts (Berland & McNeill, 2010; Driver, Newton & Osborne, 2000; Duschl, 2008; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kuhn, 1993). Attesting to the centrality of argumentation in science education, Driver, Newton, and Osborne (2000) contended that science education that excludes argumentation fundamentally misrepresents the nature of science. Engaging in argument helps students understand the importance of evidence in scientific knowledge construction (de Vries, Lund, & Baker, 2002; Driver et al., 2000; Duschl, 2000; Osborne et al., 2004; Sandoval & Reiser, 2004). Hence, for science education to mirror the practice of science, it is essential for students to learn how to engage with evidence through argumentation. Besides influencing perceptions of the theoretical nature of knowledge, argumentation in science education has practical importance. Empirical evidence suggests that students' conceptual learning of science improves when they engage in argumentation (Asterhan & Schwarz, 2007; Mercer, Dawes, Wegerif, & Sams, 2004; Sampson & Clark, 2009; Zohar & Nemet, 2002). More broadly, in teaching students how to make sense of raw data (Riegler, 2001), reconcile different plausible accounts (Sadler & Zeidler, 2005), and evaluate claims, practice in argumentation prepares students for important civic responsibilities, such as evaluating scientific arguments that bear on public policy.

Unfortunately, both preservice and inservice science teachers possess insufficient knowledge about argumentation (Wang & Buck, 2016; Zohar, 2007). NGSS implementation is still nascent, and the typical science instruction that continues to dominate science classrooms either does not promote or even conflicts with argumentation (Driver et al., 2000; Duschl & Osborne, 2002; Jimenez-Aleixandre et al., 2000). The magnitude of the shift from how science has been traditionally taught to the vision of science as argument articulated in NGSS is captured by Osbourne, Erduran, and Simon (2004), who view argumentation as a “means of transcending the dogmatic, uncritical, and unquestioning nature of so much of the traditional fare offered in science classrooms” (p. 1017). Indeed, a growing literature exploring the specific instructional practices that may support argumentation in the science classrooms recognizes that focusing on argumentation requires a deep epistemic shift from traditional science teaching and learning (Duschl, 2008; Kuhn, 2010; Sandoval, 2005) and highlights the necessity of explicit teacher instruction on science argumentation (Alvernmann, 1991; Bell & Linn, 2000; Herrenkohl, Palinscar, DeWater, & Kawasaki, 1999; Johnson & Johnson, 1988; Kuhn, 1992; Mercer et al., 2004; Osborne et al., 2004; Osborne, Erduran, Simon, & Monk, 2001; Tippett, 2009).

Teaching scientific argumentation is complex. Researchers are just beginning to identify challenges teachers encounter and understand the type of knowledge that teachers need to effectively teach argument (McNeill, González-Howard, Katsh-Singer, & Loper, 2015). For example, McNeill and Knight (2013) identified teachers’ challenges related to supporting student argumentation, including analyzing classroom discussion, integrating reasoning into the design of learning tasks, and designing argumentation questions. More recently, Christodoulou and Osborne (2014) detailed the complexity of shifting from traditional science instruction to science as argument. Recognizing this challenge, researchers have called for research on how to prepare teachers to teach to NGSS, particularly regarding the use and understanding of scientific and engineering practices (Pruitt, 2014; Wilson, 2013).

Teacher development

How can policymakers and district and school leaders help teachers make this significant shift in instruction? Long-standing evidence points to the limited efficacy of one-shot professional development efforts for durable change (Fullan & Stiegelbauer, 1991; Gusky, 1986; Howey & Joyce, 1978; Johnson, 1989; Lovitt & Clarke, 1988; McLaughlin & Marsh, 1978; Wood & Thompson, 1980). Rather, research has converged on features that make professional development more likely to be effective, including content focus, active learning for teachers, coherence with instructional context, sustained duration, and collective participation of teachers who work together in a school or set of schools (Garet, Porter, Desimone, Birman, & Yoon, 2001). Coherence is important because teachers may not use resources and strategies unless they are aligned with the other demands, constraints, and pressures under which they work. Further, the growing recognition that teachers are active agents who mediate the relationship between policies such as new academic standards or curricula and classroom practice (Lipsky, 1980; McLaughlin, 1987) points to the need to support teachers as they translate ideas about instruction into their practice (Spillane, Reiser, & Reimer, 2002).

More specifically, research has identified a number of features of successful professional development associated with student learning. Many of these center on opportunities for teachers to collaboratively make sense of how new instructional ideas can be enacted in their classrooms (e.g., Borko & Putnum, 1995; Simon, Erduran, & Osborne, 2006; Supovitz & Turner, 2000). These features include sustained opportunities for professional inquiry that model the ideal of inquiry instruction (Arons, 1989; Bay, Reys, & Reys, 1999; Borko & Putnum, 1995; Bybee, 1993; Hawley & Valli, 1999; Little, 1993; McDermott, 1990; Spillane, 1999; Supovitz & Turner, 2000) and a collaborative forum for deliberation about practice that resists the norm of privacy dominant in most schools (Spillane, 1999; Simon et al., 2006). For example, in studies of high schools in Michigan and California, McLaughlin and Talbert (2001, 2006) found that where teachers collaborated on teaching and learning and developed expertise through shared knowledge, student learning was enhanced.

As a result, educators have turned to collaborative models of teacher development (Fulton, Doerr, & Britton, 2010; Horn & Little, 2010; Mintzes, Marcum, Messerschmidt-Yates, & Mark, 2013). These opportunities take many names and forms—professional learning communities, teacher research groups, teacher inquiry groups, communities of practice, critical friend groups—but are all characterized by intentional and sustained teacher collaboration. For simplicity, we refer to these groups generally as professional learning communities, recognizing that many of the variants have specific features that are not associated with all professional learning communities.

Significance of conversational routines

Despite the popularity and promise of professional learning communities, the opportunity for intentional and sustained teacher collaboration does not guarantee generative conversation focused on problems of practice. Horn and Little (2010) documented how the different conversational routines that characterized two teacher work groups in the same school limited or supported generative teacher discussion. In one, the conversational routines were characterized by efforts to build general principles of teaching from specific problems of practice. In the other, the routine that developed around “walking through” lesson plans tended toward telling and showing what a lesson entailed rather than spurring deliberation and revision of teachers’ ideas. As a result, the second group missed opportunities to delve into the problems underlying common challenges of practice and instead focused on the more instrumental tasks of “designing, revising, and endorsing” lessons plans (p. 207). More generally, Curry (2008) noted the need for caution about the “romanticized, magical thinking” associated with professional learning communities, which can serve as a locus for learning or instead can reproduce counterproductive patterns (p. 738).

Fortunately, researchers have documented the conditions and routines associated with generative teacher conversation. Teacher professional learning communities that explicitly focus on concrete teaching tasks and student learning have the greatest impact on student learning (Curry, 2008; Darling-Hammond & McLaughlin, 1995; Little, Gearhart, Curry, & Kafka, 2003; Louis, Marks, & Kruse,1996; McLaughlin & Talbert, 2006; Phillips, 2003; Simon et al., 2006; Supovitz & Turner, 2000;). For example, a study comparing three professional development approaches to develop elementary school teachers’ instruction of electrical circuits found that students’ ability to provide justifications for why answers were correct improved only when the professional development included analysis of student conceptual understanding and implications for instruction (Heller, Daehler, Wong, Shinohara, and Mitramix, 2012).

Summarizing what is known about professional learning communities, Talbert (2010) identified key conditions for these communities to flourish: norms of collaboration, a focus on students and their academic performance, access to a wide range of learning resources for individuals and the group, and mutual accountability for student growth and success. Talbert positioned a focus on student learning as central to professional learning communities’ work:

> When teachers jointly assess the performance of their students—using disaggregated test data, formative assessment, student work, and low-inference classroom observations...They learned from their interventions what works and what needs to be changed. (Talbert 2010, p. 558)

However, Talbert also noted that teacher discussion focused on the relationship between instruction and student learning goes against the norms of collegial relations in U.S. schools, so teachers shy away from conversations that directly address these linkages (Talbert, 2010, p. 557). This acknowledgement underscores the challenge of realizing the vision of professional learning communities engaged in discussion of specific examples of problems of practice to generate, examine, and revise more general principles of teaching.

Protocols to guide teacher inquiry are one tool to address this challenge. These protocols are designed to help establish productive norms of collaboration and foster generative conversational routines within professional learning communities. Curry (2008) described how protocols “systematize and elevate the quality of CFG’s [critical friends group] oral inquiry” and encourage the deprivatization of practice by requiring members to share teaching artifacts (including examples of student work) for collective and public review (p. 764). The literature on protocol use is sparse and suggests that these formal structures can direct teachers' conversation to instruction but do not obviate the need for appropriate facilitation (Fulton et al., 2010). For example, Ermeling (2009) described them as a simple tool to help facilitators maintain the focus of a group's discussion on instruction and collecting feedback on the effects of their instruction (pg. 387).

Teachers need support to make the complex shift from teaching scientific content to teaching scientific practice. Sustained opportunities for teachers to collaborate to make sense of these new demands are a promising vehicle for professional development aimed at increasing student learning. Research suggests, however, that these opportunities for collaboration will be more successful if they maintain a sharp focus on teaching and student learning. Our suite of teacher reflection protocols is a resource to foster and support productive teacher collaboration.

Overview of the Protocol Suite

Before describing the protocol development process, we provide an overview of these resources (Exhibit 1). The suite of protocols is designed to stimulate teachers' reflection on a lesson series aimed at supporting students' science argument writing, helping teachers design and teach lessons that build students' capacity for this practice. The suite comprises a planning protocol, an assignment protocol, and a consultancy protocol (full protocols are in Appendix A). All three are designed to be used in a professional learning community, although the planning protocol can also be used individually.

- The ***planning protocol*** is designed to be used by a teacher in developing a student assignment and supporting lesson design. Teachers can use the planning protocol individually to lay out their instructional plans or consult with a group of teachers to consider the trade-offs of particular decisions in the instructional context. The presenting teacher needs to have a sense of the topic for the lesson but chooses the section of the protocol to use—writing prompt, instructional surrounds, scaffolding, or instructional sequence—based on how developed the lesson is.
- The ***assignment protocol*** supports collaborative reflection on an assignment designed to elicit a written scientific argument. A presenting teacher shares an assignment with

the group to collectively examine how the assignment brings the teacher's learning goals into practice.

- The ***consultancy protocol*** uses a group examination of student work to generate solutions to a particular issue or challenge identified by the presenting teacher.[1] After the teacher explains the context for the problem and frames the question, others in the group ask him or her two types of questions to ensure that they understand the problem and to stimulate the presenter's own thinking about it. These include clarifying short-answer questions, as well as thought-provoking probing questions. The group then discusses the problem and generates ideas to help the presenter. The presenter responds to the group members by reflecting on the ideas they suggested.

The remainder of this paper describes the protocols' development process, constructing an initial argument for their validity.

[1] This consultancy protocol is inspired by the Coalition of Essential Schools' tuning protocol (McDonald, Mohr, Dichter, & McDonald, 2013).

Exhibit 1. Teacher Reflection Protocols – Selected Questions

Protocol	**Sample question**
Planning	Does the prompt allow for more than one plausible claim? a. Yes – there are multiple plausible claims that may be supported by available evidence, and students must select one to support with evidence (contested space) b. Yes – there are multiple plausible claims, but available evidence strongly points to one (convergent) c. No – there is one plausible claim which students must support with evidence (confirmatory)
Assignment	The facilitator asks the team to first discuss the overall strengths of the assignment. He or she then moves the discussion to focus on describing the assignment as completely as possible. The protocol provides a series of questions designed to focus discussion on the discipline-specific aspects of scientific argumentation under the headers of prompt type and design, evidence and reasoning, and instructional sequencing. EVIDENCE + REASONING ● Does the writing task, as framed by the instructional surrounds, provide an opportunity for: ● Students to make sense of data? (to see relationship between data; to sift through relevant/irrelevant, supportive/unsupportive, or ambiguous data) ● Students to choose among alternative claims (and thus allow for counterclaims)?
Consultancy	The conversation should include both warm and cool comments as well as recommendations for addressing the problem. The presenter does not speak during this discussion but rather listens and takes notes. Teachers may want to consider the following aspects of writing arguments from scientific evidence: ● How did the work support/not support students in developing their claim? ● How did the work support/not support students in identifying scientific evidence? ● How did the work support/not support students in prioritizing empirical evidence? ● How did the work support/not support students in developing their reasoning? ● How did the work support/not support students in making rebuttals of competing arguments?

Context

This suite of protocols was developed collaboratively by the National Writing Project (NWP), SRI International, and the Lawrence Hall of Science as part of NWP's *Inquiry into Science Writing Project* (ISWP). Through a professional development network of nearly 200 university-based sites, NWP supports teacher leaders in studying and improving their work and sharing knowledge. This sharing enables teachers to contribute their expertise to the network and benefit from the expertise of others. Launched by NWP in response to the call for science instruction that is better aligned with current understanding of the nature of science, ISWP sought to develop teacher leaders who can support students in learning to construct written scientific arguments. ISWP consisted of two 4-day institutes for 29 teachers from five local writing project sites around the country in the summers of 2014 and 2015. These teachers also participated in an ongoing form of a professional learning community, teacher research groups (TRGs) that met monthly during 2014–15 and 2015–16 and provided a forum for the teachers to discuss and examine how to support student argument writing in science. Writing project sites varied from involving one school to several schools in the same district to multiple schools in the same state, with four to seven teachers per site. As part of their participation in the project, teachers designed and taught one lesson series each semester that culminated in an assignment designed to elicit a written argument from students and shared classroom artifacts and student work samples from these lessons both in their TRGs and with all ISWP participants via an online portal.

NWP engaged SRI and the Lawrence Hall of Science as research partners for the ISWP. The research and development component of the project was guided by principles of design-based implementation research (DBIR) (Means & Harris, 2013; Penuel, Fishman, Cheng, & Sabelli, 2011), using a collaborative approach described in the next section.

Methods

In this section, we escribe the conceptual framework we used for the protocol development process, the data collected, and the stages of analysis.

Theoretical Approach

A basic principle of DBIR is that the research and development agenda is jointly negotiated with practitioners who partner with researchers. The collaborative nature of DBIR calls for research and practice partners to engage in multiple cycles of design, implementation, and refinement. In addition, a tenet of DBIR is developing theory related to classroom learning through systematic inquiry that includes what is learned through the successes and challenges of implementation. This aspect of the DBIR framework calls for a continual assessment of the extent to which the questions that originally guided the work are still the right ones and the extent to which the anticipated outcomes are the ones most salient for participants. Finally, DBIR is concerned with developing the capacity for sustaining change in systems by increasing both researcher and practitioner capacity.

In the context of the ISWP, practitioners from NWP staff and the teacher participants collaborated with researchers from SRI and the Lawrence Hall of Science to explore students' scientific argument writing. We began the project by jointly negotiating our research and development agenda with NWP, identifying a critical problem of practice (supporting students' scientific argument writing) and a professional development and research design to support this practice. We then engaged in multiple cycles of research, design, implementation, and refinement of this agenda as the work progressed. This included revising the goals for the work and the guiding questions.

As part of the project, we developed the teacher reflection protocols based on iterative cycles of data collection, analysis, and feedback that systematically incorporated the voice of all participants (teachers and researchers) to refine the instruments. We describe this process in more detail below.

Data Collection and Analysis

We developed the suite of protocols in two stages, beginning with (1) an analysis of classroom artifacts, teacher instructional materials, and student work and then moving to (2) an iterative piloting stage. In phase 1, through a systematic review of artifacts, we identified key features of assignments that elicit different types of evidence-based science writing and of the instructional strategies that support students in this writing; these key features became the basis of the suite of protocols. In the second stage of development, we conducted think-alouds, focus groups, and observations of teachers using the protocols to refine and support validity arguments for their use.

Data for this project were collected over a 2-year period as part of the ISWP (Exhibit 2). Twice each year, teachers assembled classroom artifacts related to selected lesson series such as handouts, lesson plans, assignments, scoring guides or rubrics, marked up student work (assignments or assessments; six samples per lesson), and teacher reflections on the lesson in a collection of artifacts or "scoop" of their classroom. They posted their scoops on the project website and shared them with the other members of their TRG. The approach was modeled after the "Scoop Notebook" developed by Borko and colleagues (Borko & Stecher, 2012; Borko, Stecher, & Kuffner, 2007). These lesson scoops constituted a key data source for the phase 1 analysis. Additionally, researchers observed the summer institutes and the monthly TRG meetings at each site and conducted interviews each semester with teachers and TRG facilitators. Regularly scheduled TRG meetings (monthly for four sites, twice a month at one site) were primarily observed by phone. When possible, we observed TRGs in person during site visits twice a year. The teacher interviews focused on the scoops as a lens into teachers' lesson development process.

Exhibit 2. ISWP Data Collection

Time	Scoops	Teacher interviews	TRG observations
Fall 2014	22	26	5
Spring 2015	23	26	14
Fall 2015	21	26	14
Spring 2016	20	20	8
Total	86	98	41

Phase 1 Analysis

During phase 1 of the data analysis, researchers from SRI and the Lawrence Hall of Science systematically reviewed and coded teachers' submitted scoops across seven dimensions. In the first dimension, we considered characteristics of the prompts that teachers provided to students and then expanded this dimension to include instructional surrounds (the instructional activities of the lesson series) through the revision process. The other six dimensions captured characteristics of the work students produced in response to the prompt, namely, claim, evidence, reasoning, multiple views, scientific integrity, and overall argument. The codes were either binary (e.g., yes or no) or included more than two categories; because few of these codes were ordinal, we refer to this process as coding rather than scoring the scoops (see Appendix B for an early draft of codes related to prompt). Our reviews were in three formats: whole-group reviews by the full research team, small-group reviews by subsets of the research team, and coding sessions including NWP staff. For the small-group reviews, each group was assigned different scoops to analyze. The members of each small group were rotated so that researchers could collaboratively analyze and discuss scoops in different configurations, the intention being to generate different perspectives. During this first phase of the work, we conducted close reviews of 16 lesson scoops through two whole-group coding sessions, one coding session with NWP, and two sets of small-group coding sessions followed by full-group sessions (Appendix C).

The purpose of each review was to assess the extent to which the codes captured the important features of teachers' instructional artifacts, including student work. To this end, as we coded the assigned scoops, we documented how well the codes captured each scoop, what might be missing, and what revisions to make for the next iteration of the codes. After each session, we revised the codes to use against a new set of scoops in subsequent reviews. In addition, we solicited feedback from teachers on the codes related to prompt and instructional surrounds in two contexts. First, we observed a small group of ISWP teachers who met for a half day at NWP's fall 2014 annual meeting sort their own writing prompts based on an early iteration of the codes. Second, at the 2015 summer institute, researchers shared observations with teachers that emerged from the scoop coding and observed teachers' discussions of these findings.

Thus during phase 1, we identified the following guiding question for our analyses of the first-year lesson scoops and interviews:

What features of a writing prompt and its instructional surrounds are associated with student writing that reflects the discipline-specific elements of scientific argumentation?

The codes related to claim, evidence, reasoning, multiple views, scientific integrity, and overall argument enabled us to identify student work that demonstrated elements of scientific argumentation and then examine the features of the assignment that might have served to elicit these elements. During this first phase, we expanded the prompt-related codes to encompass the instructional surrounds of the lesson such as the evidence students were expected to draw on to respond to the prompt. This elaboration of the prompt codes reflected the fact that much of the student work submitted in the first round of scoops did not constitute scientific arguments.

Phase 2 Analysis

During phase 1, our observations of the TRGs and national calls revealed that teachers struggled to focus these collaborative conversations on specific features of student work. Thus, in phase 2 we shifted the study's focus from creating research tools to developing resources to promote reflective professional inquiry and collaboration among middle school science teachers in the context of a professional learning community. Specifically, we used the set of codes developed and refined in phase 1 as the foundation for protocols to generate productive teacher collaboration regarding support for students' science argument writing. Drawing on the key features of argument writing assignments and instructional strategies identified in our review of teacher artifacts, we generated discipline-specific questions that ISWP teachers could ask themselves in consultation with their TRGs in order to make instructional decisions to improve students' evidence-based science writing. Our guiding question for this phase of the work was

How might protocols structure teacher inquiry that supports learning and practice focused on the discipline-specific elements of scientific argumentation?

To guide refinements to the protocols in phase 2 of the analysis, researchers iteratively solicited and incorporated the voice of participants (both TRG facilitators and teachers) through interviews, think-alouds, observations, and focus groups (see Appendix C for detail). During this phase, the twice-a-year interviews with each ISWP participant concentrated more on teachers' lesson development process than they had in year 1. A subset of four participants serving as teacher leaders in their respective TRGs also participated in individual think-alouds regarding their use of the planning protocol. As part of our regular observation of the site TRG meetings and national calls, we observed six small groups of teachers use early drafts of the protocols. Additionally, we convened a subset of teachers who volunteered to participate in a session of protocol use observations and focus groups on conclusion of the 2-year professional development. Using these data, alongside additional reviews of scoops, researchers and NWP analyzed participant feedback to systematically revise the teacher reflection protocols (see Appendix C for detail). In the next section, we discuss specific examples of data and analysis from the development process to support the validity of the protocol design.

Validity Evidence

In this section, we consider the evidence for the validity of the protocols, specifically evidence that they serve their intended purpose: to stimulate generative teacher discussion about supporting students in writing scientific arguments. We begin with a description of the overall design process and a summary of the major design decisions we made. We then provide two examples to illustrate the design process, one of the ground-up development process and the other of structural revisions made after piloting the reflection protocol. The first example highlights construct validity—the evidence that the protocols address features of a writing prompt and its instructional surrounds that reflect discipline-specific elements of scientific argumentation relevant to middle school. The second example is of the revisions made to the draft protocol after observations of and feedback on initial use, in particular the decision to split the protocol into three separate protocols. Together, these elements of the design process—the close analysis of classroom artifacts and student work that formed the foundation of the protocols and the observation of and feedback on their use—constitute strong evidence for the validity of these resources.

We close this section with a discussion of the promise and limitations of the protocols: how the tools were used and under what circumstances, the usage challenges encountered by tool users, and what supports or accommodations might be beneficial to support use of the protocols as part of a professional learning community's disciplined inquiry into teacher practice and student work.

Design Process

We arrived at each design decision through an iterative process of identifying needs and posing questions, gathering and analyzing feedback and data on the proposed design, revising and refining the tools, piloting to gather further usage data, and then repeating the process (Exhibit

3). We first developed an initial teacher reflection protocol, then decided, based on initial piloting, to design three distinct protocols, and finally progressively revised core elements of each protocol based on analysis of observation, interview, and scoop data. We provide a summary of the major design decisions, and then expand on this overview by providing two cases to illustrate our design process in more detail.

Exhibit 3. Iterative Design Process

Major Design Decisions

The major design decisions in the development process, presented chronologically in Exhibit 4, show how the design process unfolded as our data analysis led us to revise the purpose and nature of the tools. Our first major design decision emerged from our analysis of the first year of teachers' scoops and TRG observations, which revealed that much of the student work teachers submitted did not constitute scientific arguments and that teachers struggled to focus their collaborative conversations on specific features of student work. This recognition identified the need for a tool that would help teachers structure and focus their TRG conversations, and led us to shift from developing researcher tools aimed at assessing middle school science argumentation to developing a teacher reflection protocol. The next major design decision, a focus on developing protocol questions related to the writing prompt, stemmed from a close analysis of the scoops to identify features of the prompt that generated more fleshed out student responses, and influenced by Berland's and McNeil's learning progression for scientific argumentation (2010). Initial piloting of the protocol led to the third major design decision, as we identified the need to develop three distinct protocols for use at different stages of developing and refining a lesson. The fourth and fifth major design decisions emerged from our analysis of the TRG meetings and national calls, and involved identifying key aspects of two of the three protocols: the assignment protocol's focus on the TRG's (rather than the presenting teacher's) close review of a planned assignment, and the consultancy protocol's emphasis on allowing the presenting teacher's concern to direct the focus of a discussion of student work.

Exhibit 4. Major Design Decisions

Design decisions	Selected steps in design process
Develop initial teacher reflection protocol	- Systematic coding of the first round of scoops demonstrated that much of student work submitted did not constitute scientific argument. - TRG observations and national calls illustrated teachers' struggle to focus conversations on specific features of student work. - Summer institute established that teachers found conversations about specific features of argument writing prompts to be generative of ideas for planning future argument writing lesson series. - Team developed, piloted, and refined reflection tool for teachers.
Focus on features of argument writing prompt	- Systematic scoop coding led team to focus on teachers' decisions for prompt wording, specific instructional surrounds, and scaffolding. - Summer institute, TRG observations, and individual interviews demonstrated that discussions of specific prompt features, such as criteria-based and explanatory prompts, supported teachers' focus on discipline-specific norms of scientific argumentation. - Berland & McNeil (2010) learning progression for scientific argumentation offered a framework that influenced the nature and specificity of protocol questions regarding instructional context, argumentative product, and argumentative process.
Develop three distinct protocols	- Piloting at NWP annual meeting and TRG observations demonstrated that initial teacher reflection protocol was long, cumbersome, and ill-suited to support teachers who were in different stages of planning and implementing a lesson series. - Team shifted to developing three distinct protocols intended to support teachers at the stages of instructional planning, assignment refinement, and reflection on student work. - Team piloted and refined protocol suite to better address teachers' needs.
Assignment protocol: TRG, not presenting teacher, describes expected student work	- TRG and national call observations revealed teachers' need for structures to help them, as a group, assess how they were bringing learning goals into practice. - Team modified the tuning protocol[a] into a protocol for developing an argument writing assignment (starting from the stages of an initial idea or a draft prompt). Emphasis placed on the presenting teacher listening to peers. - Piloting assignment protocol and subsequent focus groups underscored the value of having the teacher group (1) outline how they would respond to a draft assignment and (2) describe the assignment in detail to illuminate potential misconceptions and unintended responses for the presenting teacher.
Consultancy protocol: Presenting teacher selects focus	- TRG observations and national calls illustrated teachers' struggle to focus conversations on specific features of student work. - Team built on literature suggesting the benefits for students of teachers examining student work and the consultancy protocol (as described by McDonald et al., 2013), which provides a proven structure for guiding teacher reflection. - TRG and national call observations of piloting other protocols suggested need for the presenting teacher's concerns to dominate the conversation. - Team adapted consultancy protocol to focus on questions of scientific argumentation, framed around the presenting teacher's primary concern or question about student work.

[a] School Reform Initiative, Coalition of Essential Schools (McDonald et al., 2013)

Design Case 1: Features of Argument Writing Prompts

In the phase 1 ISWP data analysis, we found that teachers' ability to delineate the discipline-specific features of scientific argumentation in a middle school classroom was complicated by the widespread implementation of the Common Core State Standards. Science teachers were confused about how to distinguish the influence of argumentation practices oriented toward English language arts from the elements of teacher practice and student work consistent with the norms of science. To address this confusion, we developed the initial teacher reflection protocol. This protocol was intended to promote reflective professional inquiry into the discipline-specific features of scientific argumentation by focusing on the key features of writing prompts and their instructional surrounds that we identified through coding the scoops in phase 1. In this first design case, we describe our design process as it related to a specific feature of argument writing prompts: the type of prompt.

Design questions. Early in phase 1, we found that that much of the student work submitted in the fall 2014 scoops did not constitute scientific argument. Thus, as we continued our review, we began to home in on the features of a prompt that elicited writing in which students used forms of justification that are privileged in the scientific community—such as arguing from empirical evidence or science ideas—rather than reasoning more commonly accepted in English language arts—such as personal opinion or appeals to pathos.[2] Through analysis, we identified two common types of writing prompts that elicited scientific argument writing: (1) criteria-based prompts, which ask a student to determine the best categorization or best solution to a problem based on set of named or unnamed criteria, and (2) explanatory prompts, which ask a student to explain the mechanism behind a phenomenon (Exhibit 5). Criteria-based prompts are common in but not unique to engineering, where the argument demanded relates to how well a design meets various performance criteria; we saw many examples of criteria-based prompts in the natural sciences, often related to classifying an organism (see Exhibit 5).

[2] Our understanding of students' scientific reasoning and the forms of justification most acceptable in the scientific community was influenced by collaborative work between the Lawrence Hall of Science and Boston College to assess middle school students' scientific arguments (the *Constructing and Critiquing Arguments: Diagnostic Assessment for Information and Action System* project).

Exhibit 5. Observed Types of Scientific Writing Prompts[a]

Prompt type	Prompt expectations	Examples
Not an argument	- Does not require students to demonstrate "a process based on evidence and reasoning that leads to explanations acceptable by the scientific community" (NGSS Appendix F, 2013, p.13). - Summarizes the results of a scientific experiment. - Appeals to opinion, deference to authority, ethics, or aesthetics.	- Write a paper discussing the relevancy and cost of a scientific discovery.
Criteria-based prompts	- Answers the question, What is the best solution to a problem or the best categorization? - Identifies a solution, design, or definition as the best one when it most fully meets a set of named or unnamed criteria.	- Should kunan (Euglena) be classified as a plant or an animal?[b] - Is the car alive? - Which material would be best to make a life jacket from?
Explanatory prompts	- Answer the question, How or why did something happen? - Goes beyond what is directly observable to describe the processes and interactions that resulted in the observed phenomenon. - Uses principles and empirical data to get underneath the visible to explain what is happening.	- Does pollution cause asthma? - Do variations in beak size make a difference in finch survival and evolution? - How can life and conditions on Earth be used as a model for life on Mars? - Why do you think there are so many different types of living things in the world instead of just a few?

[a] See Appendix D for examples of selected instructional materials supporting scoops that represent each prompt type.
[b] Euglena is an organism that has characteristics of both plants and animals. It is classified in the Protista kingdom.

During the 2015 summer institute, researchers shared with teachers these two categorizations of prompt types and observed their subsequent discussions. Broadly, we found that examining the writing prompt was a key component of teachers' learning about the discipline-specific features of scientific argumentation. Specifically, teachers reported that they found the categorization of prompts helpful as they considered the relative complexity and difficulty of the writing assignments for students.

Design response. Teachers' reports suggested that focusing on the important pedagogical differences implied by criteria-based and explanatory prompts could generate teachers' discussion about discipline-specific elements of scientific argumentation relevant to middle school. Subsequently, when reviewing scoops we looked for distinctions in how the claims, evidence, and reasoning characterized by criteria-based and explanatory prompt differed.

Design questions. In our second-phase review of scoops, we conducted four additional rounds of small- and whole-group examination of 12 scoops to develop assertions about features of criteria-based and explanatory prompts. Distinguishing between the two types of prompts led us to consider several questions about students' specific learning needs and teachers' associated instructional decisions.

- What type of evidence would students require to successfully propose the best solution to a problem (criteria-based prompt) or to completely describe the mechanism behind a phenomenon (explanatory prompt)?
- How would students need to articulate their reasoning in order to connect evidence to their claim when referencing criteria? How would the process of articulating reasoning compare when students are tasked with describing how or why a phenomenon occurred?
- How would students know when to prioritize among multiple criteria and which criterion was most important?

An example of our discussion of criteria-based arguments was a scoop called "Kunan—Animal or Plant?" (see Appendix Exhibit D-1 for selected instructional materials). In this scoop, the writing prompt was "Should kunan be classified as a plant or an animal?" Students were given a description of an organism (*Euglena*, a protist) under the pseudonym "kunan." Successfully addressing the biological classification task in the prompt required criteria—the characteristics of animal versus plant cells—against which students made a decision about the type of organism. As students considered the characteristics of plant cells versus animal cells, they also had to prioritize among criteria. Because kunan demonstrates characteristics of both plant or animal cells, students' reasoning processes needed to include decisions about how many and which characteristics were most important to classify kunan as either an animal or plant. The kunan scoop demonstrates the potential complexity of an instructional task that requires students to marshal evidence about how well a set of criteria are met.

In contrast, the scoop "Darwin's Finches" typified a different type of argument teachers were asking students to make (see Appendix Exhibit D-2 for selected instructional materials). The writing prompt asked, "Do variations in beak size make a difference in finch survival and evolution?" Students were expected to draw on multiple sources of empirical evidence, including teacher-provided data from a study of finches and food sources and student-generated data from simulations of gathering seeds with different beak sizes, to explain how the size of a finch's beak influences its chances for survival.[3] As with other explanatory scoops, adequately arguing about the mechanism behind Darwin's finches' evolution required students to construct a chain of causal mechanisms to explain a scientific mechanism.

Our scoop analyses made clear that the type of argument prompt holds key implications for teachers' instructional practice and the features of argumentation demonstrated in student work. In successive rounds of scoop reviews, however, we found that regardless of the selected prompt type, teachers struggled to determine ways to support students in completing the writing task. Teachers continued to grapple with what types of evidence students were expected to marshal in support of claims. Additionally, teachers sought better ways to help students articulate a line of reasoning to connect multiple pieces of evidence to support their argument claims. Awareness of prompt type alone did not sufficiently guide teachers to specify their intentions for the complexity of the writing task.

Design response. To make the prompt categories more useful, we sought ways to translate the researcher-oriented questions identified above into teacher-oriented questions to guide instructional decisions relevant to each type of prompt. The learning progression for scientific argumentation articulated by Berland and McNeil (2010) offered a framework as we developed these protocol questions. Using this learning progression and the characteristics we observed in scoops, we drafted and revised questions to help teachers reflect on the intended complexity of data, argument claims, and reasoning for a lesson series.

Recognizing the need to focus productive attention on the evidence and reasoning required for either criteria-based or explanatory prompts, we drafted a combination of multiple-choice and open-ended questions to guide teachers to attend to the instructional decisions involved in selecting either prompt type (see Appendix B-1, Planning Protocol, Section 2, for more detail).

As this design case illustrates, through its close connection to student work and common and persistent problems in instructional practice, our development process was designed to ensure that the protocols focus on discipline-specific features of scientific argumentation relevant to the middle school science classroom.

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[3] This lesson was adapted from the National Science Teachers Association (2006) lesson plan "Galápagos Finches: Famous Beaks."

Design Case 2: Developing Three Protocols

This second design case illustrates the piloting and observation process we used to refine the protocols through a key decision made about their structure. In addition to the evidence from our phase 2 data analysis, their structure was guided by a tradition of designing protocols to shape teacher reflection that dates back to the 1990s. Notably, our protocol suite reflects a well-developed practice base that McDonald et al. (2013) noted was developed by teacher-scholars, popularized by school reform practitioners, and implemented by educators (p. xiii). In particular, the tuning protocol and consultancy protocols from the School Reform Initiative and the Coalition of Essential Schools offered a proven structure for guiding teacher reflection that we adapted to focus on questions of scientific argumentation. Each protocol describes the intended purpose of the group work, then walks participants through the timing, roles, and process recommended for looking at student or teacher work.

Design questions. From November 2014 to January 2015, we piloted the teacher reflection protocol with three groups of 5–10 teachers, presenting the tools to teachers for the first time and observing their use. The range of feedback we received is summarized in Exhibit 6.

These three pilots revealed that although the teacher reflection protocol did generate rich discussion of a teacher's instructional decisions to support scientific argumentation writing, it was (1) too long and cumbersome and (2) did not equally support teachers who were in various stages of planning, teaching, and reflecting on a lesson and student work.

Exhibit 6. Feedback on Teacher Reflection Protocol (Iteration 1)

Activity	Feedback	Emergent design needs and questions
November 2015 Annual Meeting	- Initial reaction to the protocol was positive. - Breaking into two small groups facilitated conversation between presenting and listening teachers. - Protocol questions were helpful to support reflection on the presenting teacher's decisions. - Protocol was too long to complete in 1 hour.	- Tension between a shorter tool that can support lesson planning and a tool that can support sustained professional development.
December 2015 TRG Meeting	- Protocol was intimidating because of length and difficult language. - Protocol was too long to complete in one meeting; it was difficult to complete Section 1: The Prompt in 1 hour. - Appreciated multiple-choice questions, which facilitated reflection on specific options for instructional practice, instead of open-ended questions.	- How do we resolve the tension between offering a tool that can be used in one meeting and retaining all sections that generate reflective discussion? - Need to define terms (argument writing features and forms of scientific justification).
January 2016 TRG Meeting	- Continuing with protocol was not helpful to the original presenting teacher, who had already begun teaching the lesson series. - Instead of continuing to use the protocol, the group split, using the protocol to help two different teachers design argument writing prompts. - Suggested additional options regarding forms of justification in an argument.	- How do we structure a resource to be useful to teachers who are at different stages of planning, refining, and reflecting on a lesson?

Design response. In response to these challenges faced by teachers using the tool, we split the teacher reflection protocol into two tools: an instructional planning tool to design a lesson series and a reflection tool to consider a completed lesson series and student work.

Design questions. After developing the two protocols, we attempted to map their intended uses back to the teachers' primary challenges. As we considered the student stumbling blocks that teachers had identified in interviews, observations, and scoop reflections—specifically, distinguishing between evidence and reasoning, incorporating data into arguments, drafting claims, and making counterarguments—we realized that the planning and reflection protocols did not fully address their needs. The planning protocol offered a wide-ranging scaffold for teachers to think through how many elements of their intended instructional decisions facilitated scientific argumentation. The reflection protocol offered an opportunity for teachers to collectively examine student work at the end of the lesson series. However, we had not created a tool that allowed for a focused conversation about the specifics of the writing assignment itself. Further, we observed that in its breadth, the planning protocol often led TRGs to focus on a different element of argumentation than intended by the presenting teacher. The reflection protocol had the potential to function similarly. These two protocols did not create a means for teachers to identify the specific challenges students might encounter in addressing the assigned writing prompt.

Design response. These findings prompted us to create three distinct protocols to support teachers at the stages of instructional planning, assignment refinement, and reflection on student work. All three protocols allow a presenting teacher to focus on different features of argument writing in science and the instructional supports necessary for students to write a scientific argument. Each protocol includes a scenario and description of, as well as purpose and process for, its use.

Exhibit 7. Unique Contributions of Teacher Reflection Protocol Suite (Iteration 3)

Protocol	**Contribution to the field**
Planning	New tool for teachers to consider the discipline-specific instructional features necessary to design an argument writing lesson series. *Teacher Preparation Worksheet* *Section 1. The Prompt* *Section 2. Instructional Surrounds* *Section 3. Scaffolding/Instructional Sequencing*
Assignment	New tool, built on tools familiar to the field, to fulfill the need for teachers as a group to assess how they are bringing learning goals into practice. Teacher group describes as completely as possible the following affordances of the writing prompt and the type of student work likely to be elicited: - features of the prompt type and design - evidence and reasoning - instructional sequencing.
Consultancy	Revised tool, based on established consultancy protocols, that is tailored to support reflection and instructional problem-solving specific to scientific argument writing. *Presenting teacher listens to warm and cool feedback on how their work supported/did not support students' in* - developing their claim - identifying scientific evidence - prioritizing empirical evidence - developing their reasoning - making rebuttals of competing arguments.

Design questions. Starting in March 2016, we shared the revised protocol suite (planning, assignment, and consultancy protocols) with all ISWP participants. Through June 2016, we observed eight groups of 4–10 teachers using each protocol. We also gathered feedback on the protocol through individual interviews of all ISWP participants and two focus groups of 3 to 4 selected volunteers. We found that while teachers appreciated the specificity of the planning protocol, its length continued to present a barrier. Most teachers did not have time to work through the entire protocol, whether using it individually or in groups. This feedback indicated a need to resolve the tension between offering a tool that could be used within a typical 45- to 60-minute meeting and retaining sections of the protocol that generated reflective discussion.

Design response. To retain the sections of the planning protocol that teachers reported to be valuable while scaling it down for use in a limited time period, we reconceived the group usage of the protocol. Some teachers had reported their experience or intention to focus on selected portions of the planning protocol during individual use. Extending this idea, we changed the directions for group use to explicitly make the tool modular. Instead of presenting the entire planning protocol as sections to be used sequentially, we revised the instructions to guide the group to the most relevant section. In the revised process, the presenting teacher would complete the Teacher Preparation Worksheet to determine a desired area of focus for their instructional planning and the TRG would proceed to the relevant section of the planning protocol. For example, if the presenting teacher expressed a need to develop specific supports for students to answer the prompt, the TRG would examine the questions presented in "Section 3: Scaffolding/Instructional Sequencing" (see Appendix Table B-1 for detail).

As this design case illustrates, the development process was responsive to the need for differentiated tools to guide the teachers' planning for, refinement of, and reflection on an argument writing lesson series.

Promise and Limitations of the Protocols

Collectively, the decisions and responses throughout our protocol design process, exemplified in the two design cases, provide evidence that the protocols have promise for stimulating teacher reflection on how to support science argument writing in middle school. They also provide evidence about how teachers may use the protocols to closely analyze the features of their writing prompts and instruction. Below, we summarize this evidence in the discussion of the promise and limitations of the protocols.

Facilitation Tools

Our analysis suggests the protocols function well as facilitation tools to focus professional learning community discussions on a presenting teacher's needs. In group pilots, we observed facilitators using the protocols to establish norms for analyzing teacher and student work among teachers. As one teacher noted, "Being able to first try and clarify my own thinking around [the scoop] by using the protocol and then having feedback from others going through the protocol was very helpful." Teachers valued that the protocols kept conversations focused on the presenting teachers' questions and identified instructional needs, and they saw this aspect as critical to teachers' acceptance of the protocols.

New teacher evaluation systems could encourage the use of the protocol suite as facilitation tools. For example, Delaware's teacher evaluation system requires evidence of teacher reflection. One ISWP teacher leader noted that this evidence can be hard to document but could be fulfilled by notes from a professional learning community meeting using one of the protocols. Another teacher described plans to use the assignment protocol with her colleague, who did not participate in ISWP, to fulfill the Massachusetts evaluation system requirement to provide evidence of examining student learning objectives.

Teachers also noted, however, that some teachers may be resistant to opening their lessons up to feedback from colleagues and cautioned that protocol use mandated by a district or school would most likely fail. These concerns align with norms of instructional privacy in schools, where teachers become habituated to planning, teaching, and assessing lessons without systematic input from their peers. On the basis of early teacher interviews, we considered that the reflection elicited by the protocols may be unfamiliar to science teachers compared with teachers in less positivistic disciplines and would therefore require careful facilitation. In more recent follow-up interviews, some teachers noted that after principals and instructional coaches modeled the use of the Coalition of Essential Schools' tuning protocol with instructional leadership teams, they were less concerned about their fellow science teachers' willingness to use this suite of reflection protocols. Collectively, questions about colleagues' receptiveness to using protocols point to a need to further develop guidance for facilitators.

Capacity-Building Tools

Hesitation to use protocols can also be addressed by demonstrating their potential to support teachers' pedagogical development. The protocols can be used as capacity-building tools by a group of teachers interested in improving their practice and exploring issues of evidence-based science writing, helping teachers surface important areas of focus, and supporting teachers as they learn to teach scientific argumentation. As teachers gain familiarity with the discipline-specific expectations of writing arguments, the protocols may also serve as the basis for development of formal assessments and additional tasks aligned with new science standards.

Teachers found protocol questions using the typology of criteria-based versus explanatory prompts offered valuable leverage to inspect differences in the kinds of evidence students draw on in support of their claim and how they engage in science ideas to connect multiple pieces of evidence to support the claim. Teachers reported that using the protocols and questions about specific prompt types and their respective instructional surrounds prompted them to develop and articulate their rationale for instructional design decisions. We observed that in one TRG, meetings where the group used the planning protocol resulted in more specific discussion of teachers' pedagogical choices, such as implications of specific word choice for prompt clarity, the affordances of writing directed to different audiences, and the trade-offs of selecting a prompt with a single correct response versus one allowing multiple plausible claims.

A potential barrier to the protocols use as capacity-building tools is the perception, reported by some teachers, that the protocol structure can constrain discussion or teacher decisions. These teachers suggested the differential value of the protocols—particularly the planning protocol—depending on an individual's teaching experience, noting that they were more inclined to use the planning protocol as a checklist of reminders of features of scientific argumentation than a tool for detailed lesson planning. These observations could reflect the fact that more experienced teachers may not approach lesson planning as formally as the planning protocol implies. Similar to the concerns about teachers' receptiveness to using protocols, the differences in how experienced teachers and novice teachers perceive their planning needs may also be tied to the private nature of teaching. If experienced teachers are accustomed to expectations that they must be an expert in all aspects of their work, they may be less inclined to consider the detailed structure of a protocol to be helpful to their work. However, the NGSS expectations for teaching students to engage in scientific argumentation are still new to the field, suggesting the protocols may have broad value regardless of a teacher's experience level. As one teacher, reflecting on her initial perception of argumentation, shared, "Just what argument writing is, going into [ISWP] I didn't know what it was. I came prepared for that [first] summer institute with a list of all these topics—Should cell phones be used in class? Should animals be used in a circus?—and so I came up with this whole idea of them writing arguments; and then I realized that's all opinion based, it's not evidence based, and that's not what argument writing is in science." Many ISWP teachers reported that the protocols stimulated their reflection on elements of scientific argumentation teachers have not previously considered.

In interviews, teachers suggested the protocols could be enhanced with videos modeling teachers using them to encourage detailed discussions of science argument writing. NWP is developing videos that show ISWP teachers using the protocols and reflecting on their value to support teachers' learning. These videos may assist in conveying the capacity-building function of the tools to science teachers outside ISWP.

Bridging Tools

We see preliminary evidence that the protocols catalyze teachers to probe and refine their instructional practice. They can be viewed as bridging tools, connecting professional development and practice. One ISWP teacher described how repeatedly using the planning protocol with her TRG and other ISWP teachers generated insight into her writing prompt development. Through this process, the teacher reported learning "how to develop a prompt and what goes into it and how much revision is necessary when you're creating a prompt. Something so simple, it seems like, 'Oh, you could do that no problem,' but it's a lot of polishing and polishing until it feels just right." After she taught the lesson series, her TRG discussed the value of unpacking the prompt as a team, furthering the group's learning.

A major challenge to the use of the protocols as bridging tools is the perception among colleagues, as reported by teachers, that argument writing is not the responsibility of the science teacher. We found that this conception often stems from an emphasis on the mechanics of writing or instructional leaders' focus on the forms of evidence and reasoning emphasized by the Common Core. However, we observed that when teachers used the protocols to translate their professional learning into practice, the tools could ground them in breaking down the components of argumentation as articulated in the NGSS practice standards.

A potential limitation to the effectiveness of the protocols is the time required for teachers to develop a common language and shared understanding of the elements of scientific argumentation. Several ISWP participants noted the challenges in attempting to apply newly acquired conceptions of argumentation while teachers were continuing to refine their understanding of the elements of a scientific argument. One facilitator suggested that teachers would benefit from 2 years of systematic inquiry into the features of student work and teacher practice before attempting to use the protocols. Another teacher leader shared her reservations that her TRG would run out of time to use the protocol series together, noting "If we had one more year I think these would be helpful—I'm struggling to see how it will be incorporated this year." Despite the increasing attention on argumentation in science education, investing time in improving one among many NGSS practice standards might create a barrier to teachers' use of the full protocol suite.

Each use scenario—facilitation, capacity-building, and bridging—suggests different trade-offs for teacher investment in the epistemic and instructional shifts entailed in the protocol series. Ultimately, while the protocol suite has promise to stimulate generative teacher discussion on supporting students in writing scientific arguments, these protocols may not be right for everyone or in all contexts.

Implications and Conclusions

We developed the suite of protocols to support teachers as they learn to teach the practice of scientific argumentation. These protocols are designed to focus teacher collaboration on the key elements of writing prompts and instructional surrounds that elicit scientific arguments. Given the evidence of the importance of conversational routines in teacher collaborative learning, the protocols aim to guide teachers to discuss specific problems of practice and examples of student learning.

Although most of our attention was on developing and refining the protocols, we did gather feedback about how the protocols could be taken up by teachers. This preliminary evidence suggests that teachers may struggle to translate their intention into actual use of the protocols with other teachers. Teachers need opportunities to work through how they can enact new standards in their classroom practice. Given the competing demands on their time, teachers have limited opportunity to collaborate. The growing emphasis on teacher evaluation may provide an opportunity to build protocol use into teachers' routines. Some teacher evaluation systems require evidence of reflection on practice. Although the imposed or required use of protocols is unlikely to be fruitful, we offer these protocols as one option for teachers to use when seeking to provide evidence of reflection.

More work remains to be done to explore how teachers take up and use these tools in the field. Researchers from SRI and the Lawrence Hall of Science will continue to track a subset of ISWP participants for 2 years to document the extent to which they maintain a focus on scientific argumentation after the program's end. This work is also addressing teacher leadership and the extent to which ISWP participants take on formal or informal leaderships roles that catalyze and support professional learning in their schools and professional communities. As part of this work, we will document how and under what conditions teachers use the protocol suite to support professional learning regarding scientific argumentation.

Future proposed research would help us explore the resources necessary to support effective facilitation of the protocols, the impacts of the protocols on teachers' beliefs and instructional practice, and resultant changes in students' argument writing practice.

References

Alvermann, D. (1991). The discussion web: A graphic aid for learning across the curriculum. *The Reading Teacher, 45*(1), 92–99.Arons, A. B. (1989). What science should we teach? In The Biological Science Curriculum Study (Ed.), *A BSCS Thirtieth Anniversary Symposium: Curriculum Development for the Year 2000* (pp. 13–20). Colorado Springs, CO.

Asterhan, C. S., & Schwarz, B. B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology*, *99*(3), 626.

Bay, J. M., Reys, B. J., & Reys, R. E. (1999). The top 10 elements that must be in place to implement standards-based mathematics curricula. *Phi Delta Kappan, 80,* 503–512.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education*, *22*(8), 797–818.

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765–793.

Biology Corner. (n.d.) *The Euglena.* Retrieved from https://www.biologycorner.com/worksheets/euglena_color.html.

Borko, H., & Putnam, R. T. (1995). Expanding a teacher's knowledge base: A cognitive psychological perspective on professional development. In T. R. Guskey & M. Huberman (Eds.), *Professional development in education: New paradigms & practices* (pp. 35–66). New York, NY: Teachers College, Columbia University.

Borko, H., & Stecher, B. M. (2012). Measuring instructional practice in science using classroom artifacts. *Journal of Research in Science Teaching*, *49*(1), 38–67.

Borko, H., Stecher, B., & Kuffner, K. (2007). *Using artifacts to characterize reform-oriented instruction: The scoop notebook and rating guide*. CSE Technical Report 707. National Center for Research on Evaluation, Standards, and Student Testing (CRESST).

Bybee, R. W. (1993). *Reforming science education: Social perspectives and personal reactions.* New York, NY: Teacher's College Press.

Christodoulou, A., & Osborne, J. (2014). The science classroom as a site of epistemic talk: A case study of a teacher's attempts to teach science based on argument. *Journal of Research in Science Teaching*, *51*(10), 1275–1300.

Curry, M. (2008). Critical friends groups: The possibilities and limitations embedded in teacher professional communities aimed at instructional improvement and school reform. *Teachers College Record, 110*(4), 733774.

Darling-Hammond, L., & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76(8),* 597.

De Vries, E., Lund, K., & Baker, M. (2002). Computer-mediated epistemic dialogue: Explanation and argumentation as vehicles for understanding scientific notions. *Journal of the Learning Sciences*, *11*(1), 63–103.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of argumentation in classrooms. *Science Education*, *84*(3), 287–312.

Duschl, R. (2000). Making the nature of science explicit. *Improving science education: The contribution of research*, 187-206.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*, 268–291.

Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse. *Studies in Science Education*, *38*, 39–72.

Ermeling, B. (2009). Tracing the effects of teacher inquiry on classroom practice. *Teaching & Teacher Education, 26(3), 377-388.*

Fullan, M., & Stiegelbauer, S. (1991). *The new meaning of educational change* (2nd ed.). New York, NY: Teachers College Press.

Fulton, K., Doerr, H., & Britton, T. (2010). STEM teachers in professional learning communities: A knowledge synthesis. *National Commission on Teaching and America's Future*.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38(4), 915-945. Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher*, *15*(5), 5–12.

Hawley, W. D., & Valli, L. (1999). The essentials of effective professional development: A new consensus. In G. Sykes & L. Darling-Hammond (Eds.), *Handbook of teaching and policy*. New York, NY: Teachers College.

Heller, J. I., Daehler, K. R., Wong, N., Shinohara, M., & Miratrix, L. W. (2012). Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. *Journal of Research in Science Teaching, 49*(3), 333–362.

Herrenkohl, L., Palinscar, A., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the Learning Sciences, 8*(3&4), 451–493.

Horn, I. S., & Little, J. W. (2010). Attending to problems of practice: Routines and resources for professional learning in teachers' workplace interactions. *American Educational Research Journal*, *47*(1), 181–217.

Howey, K. R., & Joyce, B. R. (1978). A data base for future directions in in-service education. *Theory Into Practice, 27*, 206–211.

Jimenez-Aleixandre, M., Rodrigues, A., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education,* 84(6), 757–792.

Johnson, D., & Johnson, R. (1988). Critical thinking through structured controversy. *Educational Leadership, 45*(8), 58–64.

Johnson, W. R. (1989). Teachers and teacher training in the twentieth century. In Donald, R.W (Ed.), *American teachers: Histories of a profession at work* (pp. 237-256). Washington, D.C.: American Educational Research Association.

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review, 62*(2), 155–178.

Kuhn, D. (1993). Science argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319–337.

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education*, *94*(5), 810–824.

Lipsky, M. (1980). *Street-level bureaucracy: Dilemmas of the individual in public services*. New York, NY: Russell Sage Foundation.

Little, J. W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis*, *15*(2), 129–151.

Little, J. W., Gearhart, M., Curry, M., & Kafka, J. (2003). Looking at student work for teacher learning, teacher community, and school reform. *Phi Delta Kappan*, *85*(3), 185.

Louis, K. S., Marks, H. M., & Kruse, S. (1996). Teachers' professional community in restructuring schools. *American Educational Research Journal*, *33*(4), 757–798.

Lovitt, C., & Clarke, D. (1988). *The Mathematics Curriculum and Teaching Program: Activity bank*. Curriculum Development Centre.

McDermott, L.C. (1990). A perspective on teacher preparation in physics and other sciences: The need for special science courses for teachers. *American Journal of Physics*, *58(8),* 734-742.

McDonald, J. P., Mohr, N., Dichter, A., & McDonald, E. C. (2013). *The power of protocols: An educator's guide to better practice*. New York, NY: Teachers College Press.

McLaughlin, M. (1987). Learning from experience: Lessons from policy implementation. *Educational Evaluation and Policy Analysis, 9*, 171–178.

McLaughlin, M. W., & Marsh, D. D. (1978). Staff development and school change. *Teachers College Record, 80*, 69–94.

McLaughlin, M. W., & Talbert, J. E. (2001). *Professional communities and the work of high school teaching*. IL: University of Chicago Press.

McLaughlin, M. W., & Talbert, J. E. (2006). *Building school-based teacher learning communities: Professional strategies to improve student achievement*. IL: University of Chicago Press.

McLaughlin, M. W., & Talbert, J. E. (2010). Professional learning communities: Building blocks for school culture and student learning. *Voices in Urban Education*, 27(1), 35-45.

McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2015). Pedagogical content knowledge of argumentation: Using classroom contexts to assess high-quality PCK rather than pseudoargumentation. *Journal of Research in Science Teaching, 53*(4), 527–553.

McNeil, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K–12 teachers. *Science Education*, *97*(6), 936–972.

Means, B., & Harris, C. J. (2013). Towards an Evidence Framework for Design-Based Implementation Research. *Yearbook of the National Society for the Study of Education*, 112(2), 350-371.

Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: Ways of helping children to use language to learn science. *British Educational Research Journal 30*(3), 359–377.

Mintzes, J. J., Marcum, B., Messerschmidt-Yates, C., & Mark, A. (2013). Enhancing self-efficacy in elementary science teaching with professional learning communities. *Journal of science Teacher Education*, *24*(7), 1201–1218.

National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-

12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Science Teachers Association. (2006). *Galápagos Finches: Famous Beaks*. Retrieved from http://static.nsta.org/extras/virus/Virus-Activity5.pdf.

NGSS Lead States (2013). "APPENDIX F: Science and Engineering Practices in the Next Generation Science Standards." National Research Council.

Osborne, J. F., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020.

Osborne, J. F., Erduran, S., Simon, S., & Monk, M. (2001). Enhancing the quality of argument in school science. *School Science Review, 82*(301), 63–70.

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher,* 40(7), 331-337.

Penuel, W. R., & Fishman, B. J. (2012). Large-scale science education intervention research we can use. *Journal of Research in Science Teaching*, *49*(3), 281–304.

Phillips, J. (2003). Powerful learning: Creating learning communities in urban school reform. *Journal of Curriculum and Supervision*, *18*(3), 240–258.

Pruitt, S. L. (2014). The Next Generation Science Standards: The features and challenges. *Journal of Science Teacher Education*, *25*(2), 145–156.

Riegler, A. (2001). Towards a radical constructivist understanding of science. *Foundations of Science*, *6*(1-3), 1–30.

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1), 112–138.

Sampson, V., & Clark, D. (2009). The impact of collaboration on the outcomes of scientific argumentation. *Science Education*, *93*(3), 448–484.

Sandoval, W. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*, 634–656.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, *88*(3), 345-372. doi:10.1002/sce.10130

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2/3), 235–260.

Spillane, J. (1999). External reform initiatives and teachers' efforts to reconstruct their practice: The mediating role of teachers' zones of enactment. *Journal of Curriculum Studies, 31*(2), 143–175.

Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research*, *72*(3), 387–431.

Supovitz, J., & Turner, H. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*(9), 963–980.

Talbert, J. E. (2010). Professional learning communities at the crossroads: How systems hinder or engender change. A. Hargreaves et al. (Eds.), *Second international handbook of educational change*, vol. 23 (pp. 555- 571). Springer International Handbooks of Education.

Tippett, C. (2009). Argumentation: The language of science. *Journal of Elementary Science Education, 21*(1), 17–25.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education*, *24*(1), 80–91.

Wang, J., & Buck, G. A. (2016). Understanding a high school physics teacher's pedagogical content knowledge of argumentation. *Journal of Science Teacher Education*, *27*(5), 577–604.

Wilson, S. M. (2013). Professional development for science teachers. *Science, 340*(6130), 310–313.

Wood, F. H., & Thompson, S. R. (1980). Guidelines for better staff development. *Educational Leadership, 37*(5), 374–378.

Zohar, A. (2007). Science teacher education and professional development in argumentation. In *Argumentation in Science Education* (pp. 245-268). Springer Netherlands.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*(1), 35–62

Appendix A. Teacher Reflection Protocols

Teacher Reflection Protocol Series

Developed by the National Writing Project, SRI Education, and the Lawrence Hall of Science
(Inspired by the Tuning Protocol developed by the Coalition of Essential Schools)

As science teachers increase efforts to incorporate argumentation into their classrooms, they encounter the complexity of accentuating the discipline-specific demands of scientific argumentation. In K–12, teaching students to write arguments often occurs in the context of the Common Core State Standards, particularly the expectations for an English language arts classroom. Yet science teachers face unique challenges in supporting students in developing this important disciplinary practice. Asking students to write arguments in science requires providing them with connected learning experiences that will build their understanding of evidence and why it matters to their argument. Careful planning of the learning experiences can help scaffold student success and make the instructional process less daunting. This three-part teacher reflection protocol series is designed to help teachers, in collaboration with their peers, plan, refine, and reflect on powerful learning experiences well matched to their classrooms. Teachers may view the protocol series as a tool to use with a group of colleagues.

Planning Protocol

Developed by the National Writing Project, SRI Education, and the Lawrence Hall of Science
(Inspired by the Tuning Protocol developed by the Coalition of Essential Schools)

After studying the state science standards, Ms. Nguyen considered opportunities to engage her earth sciences students in argument from evidence to demonstrate their knowledge of core disciplinary ideas and crosscutting concepts. Ms. Nguyen completed the teacher preparation worksheet and the three sections of the planning protocol to design a lesson series and then took her planning to her teacher research group. "I realized I have many choices in how to design an argument task and wanted to determine my focus. In particular, I struggled with some decisions on the instructional surrounds of the writing task—specifically, planning how to support students in rank ordering their criteria to establish the best solution to the prompt. I'd like your help to think through the options I could present my students."

After the discussion, Mr. Alvarez, one of Ms. Nguyen's science colleagues, decided to use the planning protocol in a slightly different way. He had already planned an upcoming chemistry unit based on lessons from prior years. Mr. Alvarez thought the planning protocol could be a productive tool for revising the unit to incorporate a written argument task. After completing the teacher preparation worksheet, he took it along with his existing unit plan to the next department meeting. Mr. Alvarez asked his peers to start from the beginning, with "Section 1: The Prompt," to help him think through his choices for designing a writing prompt.

Description

The planning protocol is a reflective tool that helps teachers track many threads when designing an argument writing lesson series. Teachers can use it individually to lay out their instructional plans or consult with other teachers as a group to consider the trade-offs of particular decisions in the instructional context. When the planning protocol is used by a group, the presenting teacher should prioritize one section where he or she would most benefit from collegial support.

Purpose

The planning protocol is generally used to

- Scaffold a series of decisions as a teacher designs an assignment and plans instruction.

Process

- Complete the teacher preparation worksheet to determine the desired area of focus for instructional planning.
- Given your desired area of focus, proceed to the relevant section of the planning protocol.

To focus on:	***Proceed to:***
Prompt development or students developing a claim	Section 1: The Prompt
Students' use of evidence	Section 2: Instructional Surrounds
Specific supports provided to students to answer the prompt	Section 3: Scaffolding/Instructional Sequencing

Teacher Preparation Worksheet

Important science standards

(e.g., NGSS Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts)

Among the standards relevant to your intended lesson series, list no more than **one or two** you want your peers to pay attention to in looking at the lesson:

What is the argumentative writing prompt (the question students will respond to in their writing assignment)?

What do you hope to learn from student work?

How will you support students in using empirical evidence (observations or measurements) to support the claim?

Writing scientific argumentation

Choose **one** of the following aspects of scientific argumentation in your instruction for your peers to track and provide feedback.

__ Develop a claim	__ Connect evidence to a claim	__ Articulate a line of reasoning
__ Marshall science ideas (mechanisms and principles) in support of a claim	__ Interpret data to use as evidence	__ Prioritize empirical evidence over other forms of justification
__ Connect test data to criteria	__ Evaluate the quality of test data	__ Other:

Section 1. The Prompt

This section of the protocol focuses narrowly on the writing prompt (i.e., the question students respond to) without broader consideration of the instructional surrounds. ***While completing this section, refer to the teacher preparation worksheet for the draft argumentative writing prompt.***
TYPE OF PROMPT: Is the prompt asking for an argument?
Does the prompt ask the student to make a claim a. about the extent to which a solution, design, or definition meets a set of criteria or design goals? b. about how or why some scientific phenomenon happens? c. about something that is not particularly defensible using the tools of science (e.g., a policy question about science content)? d. Students are not asked to make a claim (e.g., students describe findings from a lab).
Does the prompt allow for more than one plausible claim? a. Yes – there are multiple plausible claims that may be supported by available evidence, and students must select one to support with evidence (contested space). b. Yes – there are multiple plausible claims, but available evidence strongly points to one (convergent). c. No – there is one plausible claim that students must support with evidence (confirmatory).
AUDIENCE: Does the prompt provide students with a concrete purpose for their writing?
Who is the audience for the argument (e.g., teacher, mayor, editor, scientists)?
What role do students take (e.g., middle school students, citizens, scientists)?
PROMPT CLARITY: Are the prompt expectations clear?
Are students asked to respond to a single question or multiple questions? a. Single b. Multiple
Is the focal question clearly distinct from any other instructions or scaffolds in the prompt? a. Yes b. No
Is it clear what students should be taking a stance on? a. Yes b. No
A criteria-based prompt focuses on the extent to which a solution, design, or definition meets a set of criteria or design goals. If you are planning a criteria-based prompt, does it explicitly ask students to include why they chose certain criteria or how they prioritized criteria? a. Yes b. No an explanation of the mechanism(s) behind the criteria? a. Yes b. No why the criteria matter for the larger prompt? a. Yes b. No

This section of the protocol focuses narrowly on the writing prompt (i.e., the question students respond to) without broader consideration of the instructional surrounds. ***While completing this section, refer to the teacher preparation worksheet for the draft argumentative writing prompt.***
An explanatory prompt focuses on how or why some scientific phenomenon happens. If you are planning an explanatory prompt, does it explicitly ask students to include a description of the cause [why] and the mechanism through which it is a cause [how]? a. Yes b. No
To what extent does the prompt provide an opportunity for students to demonstrate the intended learning goals for the assignment?

Section 2. Instructional Surrounds

This section of the protocol addresses how the entire lesson series and the writing task as a whole prepare students to answer the prompt. ***While completing this section, refer to the teacher preparation worksheet for how you plan to support students' use of evidence.***
EVIDENCE + REASONING The writing task, as framed by the instructional surrounds, provides an opportunity for a. students to make sense of data (to see relationships between data; to sift through relevant/irrelevant, supportive/unsupportive, or ambiguous data). b. students to choose among alternative claims (and thus allow for counterclaims).
Is there the possibility for more than one justifiable claim (defensible with tools of science)? a. Yes b. No
Which of the following forms of evidence does the writing task call for students to draw on? __Empirical evidence (student-collected or secondary data, including from simulations) __Science ideas (e.g., accepted science concepts or models) __Plausible mechanisms __Authority __Prior experience
Does the writing task give students an opportunity to make decisions about which information to use as evidence by offering any of the following? [check all that apply] __ Ambiguous evidence that could support more than one claim __ More evidence than is necessary __ Unsupportive evidence __ Irrelevant evidence __ Students independently searching for evidence
If students use empirical evidence to support the final argument, how do they access it? a. Students are given empirical evidence. b. Students generate empirical evidence. c. Students both are given empirical evidence and generate empirical evidence. d. Students do not use empirical evidence.

<table>
<tr><td colspan="3">Teachers will make different choices about the complexity of the writing task and its instructional surrounds based on the science standards, the learning goals for the lesson series, and student needs. Use the questions below to reflect on appropriate ways to support students to successfully complete the writing task, based on the type of prompt and intended complexity of the task.</td></tr>
<tr><td>Criteria-Based Writing Tasks

How does the assignment offer students opportunities to provide a complex explanation about the extent to which something (a solution, design, or definition) meets a set of criteria or design goals?</td><td></td><td>Explanatory Writing Tasks

How does the assignment offer students opportunities to explain complex mechanisms behind a scientific phenomenon?</td></tr>
<tr><td>Consider the intended complexity of the task. Does the assignment encourage students to
a. identify a solution, design, or definition with no teacher expectation for defined criteria?
b. identify a solution, design, or definition where students are expected to define criteria?
c. articulate the merits of a solution, design, or definition relative to a single definitive criterion?
d. articulate the merits of a solution, design, or definition relative to multiple definitive criteria?
e. articulate the merits of a solution, design, or definition relative to multiple criteria that need to be rank ordered?</td><td></td><td>Consider the intended complexity of the task. Does the assignment encourage students to
a. identify a cause?
b. explain how a single causal chain with one or two steps leads to an outcome?
c. explain how a single causal chain with multiple steps leads to an outcome?
d. explain how multiple mechanisms interact to lead to an outcome?</td></tr>
<tr><td>How does the assignment encourage the above?</td><td></td><td>How does the assignment encourage the above?</td></tr>
</table>

Teachers will make different choices about the complexity of the writing task and its instructional surrounds based on the science standards, the learning goals for the lesson series, and student needs. Use the questions below to reflect on appropriate ways to support students to successfully complete the writing task, based on the type of prompt and intended complexity of the task.		
If there are multiple criteria that could be rank ordered (c or d), how does the writing task support students in determining/explaining their rank ordering of criteria? a. Students are expected to determine trade-offs and relative importance of various criteria independently. b. Teacher works with students (through instructional surrounds) to determine relative importance of various criteria (e.g., in an activity together). c. Teacher explicitly tells students the rank order of criteria. d. Teacher does not expect a rank ordering of criteria.		If there is a single causal chain with multiple steps (c) or multiple mechanisms that interact to lead to an outcome (d), how does the writing task support students in determining the scope of the mechanism? a. Students are expected to determine independently how far back to go in the causal chain to explain. b. Teacher works with students (through instructional surrounds) to determine how far back to go in the causal chain to explain. c. Teacher explicitly tells students how far back to go in the causal chain to explain. d. Teacher does not expect a particular scope of the mechanism.

Section 3. Scaffolding/Instructional Sequencing

This section addresses specific supports provided to students to answer the prompt.   ***While completing this section, refer to the teacher preparation worksheet for the one aspect of scientific argumentation on which you would like your peers to focus and provide feedback.***
A. Presenting Teacher: Answer the following two questions before presenting to your colleagues.   What strategies might you consider to support your students in answering the prompt?
What types of scaffolding have been effective with this group of students in the past?
Considering past argumentative and/or writing assignments (with these students or others), what scaffolds might your students need for this lesson series?

This section addresses specific supports provided to students to answer the prompt.

While completing this section, refer to the teacher preparation worksheet for the one aspect of scientific argumentation on which you would like your peers to focus and provide feedback.

B. Teacher Research Group: Keeping in mind the one focal aspect of scientific argumentation the presenting teacher selected, what scaffolds might that teacher use to support students in answering the prompt?

How will students have an opportunity to...	learn important science standards (e.g., NGSS Disciplinary Core Ideas, Practices, and Crosscutting Concepts)?	use empirical evidence in this lesson series?	develop their practice of scientific argumentation?
Read		e.g., read data charts	e.g., read several sample claims e.g., read to find evidence of an author's reasoning
Listen			
Talk			e.g., in groups, share draft claims
Write	e.g., keep an ongoing science notebook e.g., keep anchor charts in the class to track key science ideas	e.g., use sentence stems to write about evidence	
Build/model		e.g., build a model using empirical evidence	
Experiment/ demonstrate			
Respond/revise		e.g., respond to new evidence	e.g., revise claim or other argument based on peer feedback

Key Terms

- Claim: an answer to a question about how or why something happens or about how an idea (or design) meets a set of criteria (or design goals)
- Evidence: information leveraged to support or refute a claim
- Reasoning: the process of drawing logical connections between evidence and claims, among disparate pieces of evidence, or supporting inferences from data in relation to a claim
- Counterclaim: an alternative answer to a question about how or why something happens or about how an idea (or design) meets a set of criteria (or design goals)
- Rebuttal: critique of evidence or reasoning used to justify a claim or of evidence mounted in opposition to an existing claim or in support of a proposed counterclaim
- Stance: a clear position on a claim in a contested space
- Prompt: the question students respond to
- Writing task: the culminating evidence-based writing assignment for the lesson series
- Instructional surrounds: the instructional activities of the lesson series
- Criteria-based argument: a claim justified by evidence about which solution best meets a set of criteria or how well a particular solution meets a set of criteria
- Explanatory arguments: a claim justified by evidence about which causal mechanism best explains how or why an observed phenomenon works
- Warrant: the reasons (rules, principles, etc.) that are proposed to justify the connections between the data and the knowledge claim or conclusion (Driver, Newton, & Osborne, 2000)[4]

Forms of Justification

- Empirical evidence: using observations or measurements to support the claim
- Science ideas: using scientific concepts that support the claim
- Authority: appealing to what an expert or scientist said to support the claim
- Prior experience: appealing to something students have previously seen or felt to support the claim
- Plausible mechanism: contriving a process (mechanism) to make sense of a phenomenon but that is not necessarily scientifically accurate

[4] Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of argumentation in classrooms. *Science Education*, *84*(3), 287–312.

Assignment Protocol

Developed by the National Writing Project, SRI Education, and the Lawrence Hall of Science
(Inspired by the Tuning Protocol developed by the Coalition of Essential Schools)

Ms. Meyer's physical science students were just completing their unit on plate tectonics. As part of the concluding unit, Ms. Meyer was planning to assign a final argument essay. She decided to take the assignment to her teacher research group and ask the teachers to use the assignment protocol to help her analyze it before she gave it to students.

Features of Argumentation

The presenting teacher may frame the problem/question as supporting students to

- Develop a claim
- Identify scientific evidence
- Prioritize empirical evidence
- Articulate their reasoning
- Make rebuttals of competing arguments.

Description

The assignment protocol is specifically for teacher assignments. Although teachers can often effectively examine their assignments by looking at their students' work, they also need to assess as a group how they are putting learning goals into practice. This protocol provides teachers with collegial support as they plan units that challenge students and help them meet their learning goals.

Purpose

The assignment protocol is generally used for

- Assessing whether an assignment asks students to explain, manipulate, synthesize, generalize, hypothesize, or infer
- Determining whether a unit helps students address big ideas, concepts, and themes
- Analyzing whether students are required to use different habits of mind.

Process

Time: 60 minutes –The time may be expanded or shortened by adjusting the times for probing questions, the group discussion, or the presenter's response.

Roles: Presenter – Person who brings the issue and work to be discussed by the group.

Facilitator – Person who moves the group through the protocol, watches the time, monitors probing questions, and balances warm and cool feedback. The facilitator may also participate.

Procedure

1. **Presenter describes the assignment (10 minutes)**
   The presenter describes his or her objectives, the context for the assignment, and how it fits into the overall plan for the semester.
2. **Group asks clarifying questions (5 minutes)**
   Clarifying questions have short, factual answers. The presenter responds briefly to each.
3. **Facilitator asks the group members to outline how they would respond to the assignment (10 minutes)**
   The facilitator asks the teachers to consider how they would complete this assignment by taking a few minutes to outline what their response would be.
4. **Facilitator asks the group to look at the assignment (10 minutes)**
   The facilitator asks the teachers to first discuss the overall strengths of the assignment. He or she then focuses the discussion on describing the assignment as completely as possible from their perspectives.

   PROMPT TYPE AND DESIGN
   - ❏ Does the prompt ask students to make a claim?
   - ❏ Is it clear what students should be taking a stance on?
   - ❏ Does it allow for more than one plausible claim?
   - ❏ Who is the audience for the argument?
   - ❏ How do students understand the purpose for writing the argument?
   - ❏ Are students invited to assume a role in writing their argument?

   EVIDENCE + REASONING
   - ❏ Does the writing task, as framed by the instructional surrounds, provide an opportunity for
     - ❏ Students to make sense of data (to see relationship between data; to sift through relevant/irrelevant, supportive/unsupportive, or ambiguous data)?
     - ❏ Students to choose among alternative claims (and thus allow for counterclaims)?

   INSTRUCTIONAL SEQUENCING
   - ❏ Does the instructional sequence provide scaffolds to support evidence-based writing and to support learning of science concepts?
   - ❏ Are students supported in using the following forms of justifications?
     - ❏ Empirical evidence ❏Science ideas ❏Plausible mechanisms
   - ❏ Where will students have an opportunity to use empirical evidence in this lesson series?
   - ❏ Do scaffolded activities target specific, discrete aspects of argumentation (e.g., developing a claim, marshaling evidence, or articulating reasoning) based on student understanding, misconceptions, or challenges?
5. **Presenter responds to the discussion (10 minutes)**
   The presenter responds to the discussion by restating what he or she heard. The teacher may identify changes he or she will make or decide to come back at a later date with changes.

Key Terms

- Claim: an answer to a question about how or why something happens or about how an idea (or design) meets a set of criteria (or design goals)
- Evidence: information leveraged to support or refute a claim
- Reasoning: the process of drawing logical connections between evidence and claims, among disparate pieces of evidence, or supporting inferences from data in relation to a claim
- Counterclaim: an alternative answer to a question about how or why something happens or about how an idea (or design) meets a set of criteria (or design goals)
- Rebuttal: critique of evidence or reasoning used to justify a claim or of evidence mounted in opposition to an existing claim or in support of a proposed counterclaim
- Stance: a clear position on a claim in a contested space
- Prompt: the question students respond to
- Writing task: the culminating evidence-based writing assignment for the lesson series
- Instructional surrounds: the instructional activities of the lesson series
- Criteria-based argument: a claim justified by evidence about which solution best meets a set of criteria or how well a particular solution meets a set of criteria
- Explanatory arguments: a claim justified by evidence about which causal mechanism best explains how or why an observed phenomenon works
- Warrant: the reasons (rules, principles, etc.) that are proposed to justify the connections between the data and the knowledge claim or conclusion (Driver, Newton, & Osborne, 2000)[5]

Forms of Justification

- Empirical evidence: using observations or measurements to support the claim
- Science ideas: using scientific concepts that support the claim
- Authority: appealing to what an expert or scientist said to support the claim
- Prior experience: appealing to something students have previously seen or felt to support the claim
- Plausible mechanism: contriving a process (mechanism) to make sense of a phenomenon but that is not necessarily scientifically accurate

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[5] Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of argumentation in classrooms. *Science Education*, *84*(3), 287–312.

Consultancy Protocol

Developed by the National Writing Project, SRI Education, and the Lawrence Hall of Science
(Inspired by the Tuning Protocol developed by the Coalition of Essential Schools)

Ms. Stone, the biology teacher, brought four arguments from her students, along with the graphic organizer that she gave them, to her teacher research group. "Look at the data my students are using," she said. "These four are representative of the arguments I'm getting from all my students. As part of the assignment sequence to write these essays they completed a lab and used this graphic organizer to organize the data from the lab. But as you can see, none of them referenced the data in their arguments. I haven't been able to get them to incorporate the data into their writing. I'd appreciate your ideas about how I might get my students to incorporate their own collected data into their written arguments."

Description

The consultancy protocol provides the presenting teacher with assistance in solving a problem on a particular issue or challenge. The presenting teacher brings student work to the teacher research group. After the teacher presents the context for the problem and frames the question, others in the group ask the presenter clarifying short-answer and probing, thought-provoking questions to ensure that they understand the problem and to stimulate the presenter's own thinking about the problem. The group then discusses the problem and generates ideas that may help the presenter. The presenter responds to the group by reflecting on the ideas they suggested.

Features of Argumentation

The presenting teacher may frame the problem/question as supporting students to

- Develop a claim
- Identify scientific evidence
- Prioritize empirical evidence
- Articulate their reasoning
- Make rebuttals of competing arguments.

Note: This protocol is intended for use with student work. If the focus of the conversation is the assignment and there is no student work, consider using the assignment protocol.

Purpose

The consultancy protocol is generally used for

- Addressing issues in students' and/or teachers' work
- Analyzing complex dilemmas or challenges.

Process

Time: 60 minutes – The time may be expanded or shortened by adjusting the times for probing questions, the group discussion, or the presenter's response.

Roles: Presenter – Person who brings the issue and work to be discussed by the group.

Facilitator – Person who moves the group through the protocol, watches the time, monitors probing questions, and balances warm and cool feedback. The facilitator may also participate.

Procedure

1. **Presenter gives a quick overview of the work (5 minutes)**
   The presenter fully describes the context of the problem and frames a specific question for the consultancy group to consider.
2. **Consultancy group asks clarifying questions (5 minutes)**
   Clarifying questions have short, factual answers. The presenter responds briefly to each.
3. **Consultancy group asks probing questions (10 minutes)**
   Probing questions are worded to help the presenter clarify his or her thinking about the framing question. The purpose is to expand the presenter's perspective and help him or her examine the issue or dilemma. The presenter may respond, but there is no discussion by the larger group. For example, a member of the group might ask, "What would an ideal response to your writing prompt look like?"
4. **Group consults and presenter listens (15 minutes)**
   The group discusses the work and the issues that were presented, responding to questions such as
   a. What did we hear? What does the presenting teacher want us to address?
   b. What are the relevant strengths in the work or context?
   c. What are the pertinent gaps or issues related to the presenting teacher's question that have not been examined?
   d. What do we think about the questions and issues presented?
   e. What has the presenter not considered?

4. **Group consults and presenter listens (15 minutes) (Continued)**
   The conversation should include both warm and cool comments as well as recommendations for addressing the problem. The presenter does not speak during this discussion, but rather listens and takes notes. Teachers may want to consider the following aspects of writing arguments from scientific evidence:
   - How did the work support/not support students in developing their claim?
   - How did the work support/not support students in identifying scientific evidence?
   - How did the work support/not support students in prioritizing empirical evidence?
   - How did the work support/not support students in developing their reasoning?
   - How did the work support/not support students in making rebuttals of competing arguments?

   The presenter does not speak during this discussion, but rather listens and takes notes.
5. **Presenter responds and consultancy group listens (10 minutes)**
   The presenter describes what he or she heard and what resonated. The presenter shares where his or her thinking is at the moment and what next steps might be.

Key Terms

- Claim: an answer to a question about how or why something happens or about how an idea (or design) meets a set of criteria (or design goals)
- Evidence: information leveraged to support or refute a claim
- Reasoning: the process of drawing logical connections between evidence and claims, among disparate pieces of evidence, or supporting inferences from data in relation to a claim
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Forms of Justification

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- Authority: appealing to what an expert or scientist said to support the claim
- Prior experience: appealing to something students have previously seen or felt to support the claim
- Plausible mechanism: contriving a process (mechanism) to make sense of a phenomenon but that is not necessarily scientifically accurate

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[6] Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of argumentation in classrooms. *Science Education*, *84*(3), 287–312.

Appendix B. Selected Rubric Dimensions

PROMPT
Domain: teacher practice
Does the prompt [is there a clearly delineated question that] encourage students to make an evidence-based claim about scientific phenomena? (a) yes (b) no (e.g., prompt encourages a descriptive summary of findings from a lab or a restatement of a scientific principle)
Does the question create space for multiple views? (a) prompt suggests a single answer and doesn't leave space for multiple claims (b) prompt is written to suggest multiple claims are possible but ultimately only one is correct (convergent) (c) prompt allows for multiple correct claims (e.g., prompt is a contested problem space—real or simulated—and asks students to craft 1 of multiple possible claims) (divergent)
Is the prompt's primary focus to elicit an argument that is defensible with data or scientific ideas (as opposed to a moral or aesthetic argument)? (a) yes (b) no
How does the prompt scaffold the structure (claim, evidence, reasoning, rebuttal) of argument writing? (a) prompt is highly scaffolded (e.g., breaks down each component of an argument and asks students to respond to them separately) (b) prompt provides some mention of the components of an argument but does not ask students to respond to each one separately (e.g., prompt includes sentence frames or "text clues") (c) prompt asks a question without defining what the teacher expects to see in students' responses (i.e., doesn't ask explicitly for claim, evidence, reasoning)
How intentional is the support for evidence-based writing? (a) There is a curricular build to support learning of relevant scientific concepts AND evidence-based writing (b) There is a curricular build to support learning of relevant scientific concepts BUT NOT evidence-based writing (c) There is a curricular build to support evidence-based writing BUT NOT learning of relevant scientific concepts (d) There is NO curricular build to support evidence-based writing OR learning of relevant scientific concepts
Audience (a) teacher or no audience (b) targeted audience (e.g., mayor, editor)
What question are students answering? (e.g., compare/contrast, defend conclusion from experiment, competing mechanisms) [open-ended coding until patterns emerge]

Appendix C. Data Collection and Analysis

Table C-1: Data Collection Protocol Feedback

Timing	Teachers	Activity	Purpose	Focus
November 2015	10	Annual meeting	Pilot initial reflection protocol	Present first draft protocol and observe use
December 2015	5	TRG observation	Pilot initial reflection protocol	Observe TRG use of initial reflection protocol
January 2016	5	TRG observation	Pilot initial reflection protocol	Observe TRG use of initial reflection protocol
January 2016	4	Think-alouds	Gather teacher feedback on first draft planning protocol	Detailed reactions to, and questions about, planning protocol items
February 2016		National calls (3)	Pilot group use of planning protocol	Present planning protocol to all ISWP participants and observe use
February 2016	4	TRG observation	Pilot group use of planning protocol	Observe TRG use of planning protocol
March 2016	9	TRG observation (2)	Pilot group use of planning protocol	Observe TRG use of planning protocol
March 2016	2	Small-group scoop analysis	Analyze scoops designed with planning protocol	Analyze for influence and revision of planning protocol
April 2016	4	TRG observation	Pilot group use of assignment protocol	Observe TRG use of assignment protocol
June 2016	7	Summer convening	Pilot group use of protocol series	Testing and revision of teacher reflection protocol series
November 2016	5	Interviews	Gather data on motivation for protocol use	Identify current and intended use of protocols, including initial reactions from colleagues

Table C-2: Phase 1 Data Analysis

Analytic round	Time	Scoops analyzed	Activity	Purpose	Focus
1	November 2014	3	Researcher coding session (group)	Test and refine scoring process	Norm on artifact coding process
2	November 2014	1	Coding session with NWP	Inform annual meeting	Reflect on teacher practice as revealed by scoops
3	January 2015	n/a	Code revision	Refine rubrics	Revise codes based on November 2014 findings
4	February 2015	2	Researcher coding session (group)	Refine rubrics	Norm on categorical scoop coding to refine codes & give formative feedback
5	February 2015	6 (3 each)	Small-group coding	Refine rubrics	Norm on categorical scoop coding to refine codes & give formative feedback
6	February 2015		Researcher coding session (group)	Refine rubrics	Norm on categorical scoop coding to refine codes & give formative feedback
7	March 2015	6 (3 each)	Small-group coding	Refine rubrics	Norm on categorical scoop coding to refine codes & give formative feedback
8	March 2015		Researcher coding session (group)	Refine rubrics	Norm on categorical scoop coding to refine codes & give formative feedback

Table C-3: Phase 2 Data Analysis

Analytic round	Time	Scoops analyzed	Activity	Purpose	Focus
9	August 2015	6 (3 each)	Small-group scoop analysis	Descriptive analysis of scoops	Criteria-based arguments
10	August 2015		Whole-group scoop analysis	Descriptive analysis of scoops	Criteria-based arguments
11	August 2015	6 (3 each)	Small-group scoop analysis	Descriptive analysis of scoops	Explanatory arguments
12	August 2015		Whole-group scoop analysis	Descriptive analysis of scoops	Explanatory arguments
13	September 2015	2	NWP coding session	Rubric-based and descriptive analysis of scoops	Criteria-based vs. explanatory prompts
14	October 2015	6 (3 each)	Small-group analysis	Revise rubrics into initial reflection protocol	Criteria-based vs. explanatory prompts
15	October 2015		Whole-group analysis	Revise rubrics into initial reflection protocol	Criteria-based vs. explanatory prompts
16	November 2015	2	Annual meeting analysis	Revise protocol	Synthesize and apply teacher feedback to initial reflection protocol
17	December 2015	1	TRG observation	Revise protocol	Synthesize and apply teacher feedback to initial reflection protocol
18	January 2016	1	TRG observation	Revise protocol	Synthesize and apply teacher feedback to initial reflection protocol
19	January 2016	4	Think-alouds: planning protocol	Revise planning protocol	Gather detailed individual reactions to, and questions about, planning protocol items
20	February 2016	3	National calls: planning protocol	Revise planning protocol	Gather group reactions to, and questions about, planning protocol items
21	March 2016	1	TRG: planning protocol	Revise planning protocol	Gather group reactions to, and questions about, planning protocol items
22	March 2016	2	Small-group scoop analysis	Analyze scoops designed with planning protocol	Analyze instructional artifacts for influence and revision of planning protocol
23	May 2016	n/a	Site visit debriefs	Analyze interview data on use of protocols	Form assertions based on detailed individual reactions to, and questions/suggestions about, teacher reflection protocol series
24	June 2016	6	Summer convening	Revise protocol series	Testing and revision of teacher reflection protocol series

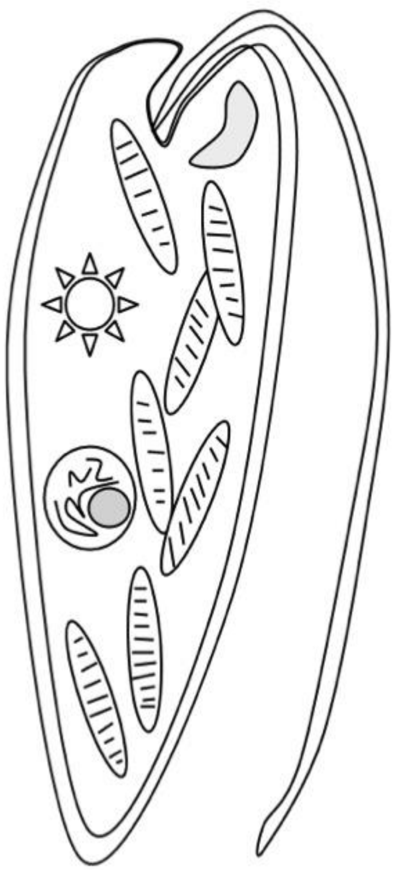
Appendix D. Selected Scoop Instructional Materials

Exhibit D-1: Kunan - Animal or Plant?[7]

The Kunan

Color the Kunan according to the directions. Organelles can be identified based on their descriptions and locations

All kunan have chloroplasts and can make their own food by photosynthesis. They are not completely autotrophic though, kunan can also absorb food from their environment; kunan usually live in quiet ponds or puddles.



Kunan move by a flagellum (plural , flagella), which is a long whip-like structure that acts like a little motor. The flagellum is located on the anterior (front) end, and twirls in such a way as to pull the cell through the water. It is attached at an inward pocket called the reservoir. **Color the reservoir grey and the flagellum black.**

The Kunan is unique in that it is both heterotrophic (must consume food) and autotrophic (can make its own food). Chloroplasts within the kunan trap sunlight that is used for photosynthesis, and can be seen as several rod like structures throughout the cell. **Color the chloroplasts green**. Kunan also have an eyespot at the anterior end that detects light, it can be seen near the reservoir. This helps the kunan find bright areas to gather sunlight to make their food. **Color the eyespot red.** Kunan can also gain nutrients by absorbing them across their cell membrane, hence they become heterotrophic when light is not available, and they cannot photosynthesize.

The kunan has a stiff pellicle outside the cell membrane that helps it keep its shape, though the pellicle is somewhat flexible and some kunan can be observed scrunching up and moving in an inchworm type fashion. **Color the pellicle blue**.

In the center of the cell is the nucleus, which contains the cell's DNA and controls the cell's activities. The nucleolus can be seen within the nucleus. **Color the nucleus purple, and the nucleolus pink.**

The interior of the cell contains a jelly-like fluid substance called cytoplasm**. Color the cytoplasm light yellow**. Toward the posterior of the cell is a star-like structure: the contractile vacuole. This organelle helps the cell remove excess water, and without it, the kunan could take in so much water due to osmosis that the cell would explode. **Color the contractile vacuole orange**.

1 of 2

[7] The worksheet "The Kunan" was adapted from the Biology Corner (n.d.) worksheet "The Euglena."

Answer the following questions:

1. Are kunan unicellular or multicellular? ____________________________

2. What organelle carries out photosynthesis? ____________________________

3. On which end is the flagellum located? ____________________________

4. Define autotrophic. ____

5. Define heterotrophic. ____

6. Describe the two ways in which the kunan get their nutrients.

   a) ____

   b) ____

7. What is the function of the eyespot used for? ____

8. What is the function of the nucleus? ____

9. What is the function of the contractile vacuole? What would happen if the cell did not have this organelle? ____

____

____

Name ____________________ Period ____

Kunan Science Argument

QUESTION	
Should kunan be classified as a plant or an animal?	
CLAIM	
EVIDENCE	REASONING
COUNTER CLAIM	

Science Argument chart

Exhibit D-2: Darwin's Finches[8]

Battle of the Beaks

Normal Year

Beak Type	Number of Seeds
Small Beak	Test #1
Small Beak	Test #2
Total:	
Big Beak	Test #1
Big Beak	Test #2
Total:	

Normal Year

Before:

Which beak size do you think will gather the most seeds during a *normal year*?

After:

Which beak size picked up the most seeds during a *normal year*?

One year there was a drought and many plants failed to bloom and produce new seeds. All the medium ground finches ate the small, soft seeds first, leaving mostly large, tough seeds, so now big seeds dominate the menu!

Drought Year

Beak Type	Number of Seeds
Small Beak	Test #3
Small Beak	Test #4
Total:	
Big Beak	Test #3
Big Beak	Test #4
Total:	

Drought Year

Before:

Which beak size do you think will gather the most seeds during a *drought year*?

After:

Which beak size picked up the most seeds during a *drought year*?

[8] This lesson was adapted from the National Science Teachers Association (2006) lesson plan "Galápagos Finches: Famous Beaks."

Review Questions:

1. How does a change in environment (drought) affect which beak size gathers the most seeds?

2. "Natural selection" occurs when the environment favors or selects some variations over others. You have tested two variations of beaks, large and small. In the drought environment, which beak variation is favored? Why?.

Name: Period: Date:

Part One: Islands and Finches

Record beak sizes using the correct metric measurement.

Medium Ground Finch Beak Number	Beak depth in centimeters	Beak depth in millimeters* *multiply centimeters by 10 to get millimeters
Finch 1075	cm	mm
Finch 2666	cm	mm
Finch 5560	cm	mm
Finch 3527	cm	mm
Finch 5026	cm	mm
Finch 1999	cm	mm

1. How many different beak sizes did you find? ___________
2. What was the largest beak size in millimeters? __________
3. What was the smallest beak size in millimeters? __________
4. Based on the sizes of the beaks, what sorts of seed sizes do you think each of these finches can eat?
5. Which finch beak seems like it is best adapted to eat? Explain your answer.

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