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Strategies to Support Student Argument and Argumentative Writing in a Secondary STEM Classroom

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by

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Chapter I: Introduction

In the last 25 years there has been increasing frequency and urgency of calls for a change in science education towards one which is more reflective of the best practices of science teaching found in education research. Starting with *The Benchmarks for Scientific Literacy* (AAAS, 1993), the push has been toward actively *doing* science in order to *learn* science. By engaging in the practices of science, students have a better understanding of the nature of science, the way knowledge is constructed, and the scientific concepts themselves. Argumentation is a key aspect of these practices, and multiple studies have shown the link between learning to construct sophisticated arguments and learning scientific concepts (Erduran & Jiménez-Aleixandre, 2008; Dunac & Demir 2013).

Furthermore, *The Benchmarks for Scientific Literacy* describe the process of scientific investigation as "the collection of relevant *evidence*, the use of logical *reasoning*, and the application of imagination in devising hypotheses and *explanations to make sense of collected evidence*" (AAAS, 1993, emphasis added). The process of doing science culminates in explanation: the sense making and articulation of findings in a way that can be reviewed by others in a scientific community. The *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013), expand this idea into the scientific practices of "constructing explanations," and "engaging in argument from evidence." The difference between these two practices is difficult to tease apart as the *process of argumentation* requires the collaborative *construction* of robust explanations. In this study, we combine the practices of argumentation and explanation into one: specifically, argumentation is defined as "constructing and defending scientific explanations" (Berland & Reiser, 2009, p. 28). This definition of argumentation works in conjunction with the 8th NGSS scientific practice "obtaining and communicating information" as it requires other participants in order to engage in the practices of science. These scientific practices position the learners as active participants who work collaboratively with others in the process of science.

Framing science as a collaborative process lays in stark contrast with previous views of science as a body of knowledge to be acquired by individual learners, as well as with pervasive depictions of scientists – notably Einstein – in popular culture as lone geniuses. However, this emphasis on the individual is not lost in the modern era of accountability through standardized testing. While science is a collaborative process, we are also interested in the individual growth of students in their knowledge of the process, skills, and concepts of science. This presents an interesting problem: how can we design instruction to engage students in the collaborative process of science, while still assessing each student's ability to articulate their collaborative sense-making process?

Significance

The importance of argumentation is not limited to science. In a study of all the types of writing assignments for undergraduates, Wolfe (2011) studied 173 written assignments in lower division courses representative of all of the schools at Miami University in Oxford, Ohio. They found the majority (59%) of assignments required students to engage in some form of argumentation. Also, 100% of the written assignments from the courses in the engineering school were argumentative. The need for critical use of evidence and argumentation in higher education, as well in future careers and citizenship, spurred its inclusion in the *Common Core Literacy Standards* (CCLS; NGA Center/CCSSO, 2010). Specifically, for secondary science, the CCLS standards detail the ways in which students are expected to "write arguments focused on discipline-specific content." At the highest level (11-12 grade), these written arguments should specifically include "precise, knowledgeable *claim*(s)" using "an *organization* that logically sequences the claim(s), counterclaims, reasons, and evidence," and "*clarif(ies) the relationships* between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims" (NGA Center/CCSSO, 2010, emphasis added). This detailed description is intended to make explicit the expectations of a graduating senior's argumentative writing and leaves the process of exactly how to help students write at this high level up to the teachers.

There are many different argumentation structures and routines to support argumentation published in the literature (Toulmin, 2003; Sampson et al., 2013; Berland & Reiser, 2009). However, none have studied argumentation in the specific context of a secondary STEM course.

Problem Statement

This action research study will explore the impact of specific research based strategies on students' ability to argue effectively in writing about physics content knowledge. The strategies studied include (1) inquiry embedded tasks, (2) collaborative discourse in a small group and online setting, and (3) direct teaching of the CER argumentation structure.

Terms

Argumentation - “constructing and defending scientific explanations” (Berland & Reiser, 2009, p. 28)

Discourse – written or spoken exchange of ideas

Argumentation Structures – specific organization or components of a robust argument

Argumentation Scaffolds – instructional strategies to help support students argumentation

CER – Claim Evidence Reasoning Framework (McNeill & Pimentel 2010)

Chapter II: Literature Review

Academic studies of argumentation have a long history dating back to Aristotle in ancient Greece. Furthermore, there is a large cannon of research into argumentation in science education which draw upon theoretical studies such as that of Toulmin (1958/2003). Argumentation as it is used in the secondary science classroom is the focus of this work. The following sections provide insight on (1) the use of argumentation as a practice of a scientific community, (2) the role of a specific task or activity in supporting argumentation, (3) structures and scaffolds for argumentation, (4) the social and discursive aspects of argumentation, and finally (5) use and assessment of written argumentation.

Argumentation as a Practice of a Scientific Community

Argumentation is a key aspect of a scientific community, which is primarily concerned not only with what knowledge one has gained, but also how the understanding came about through evidence and clear logical reasoning which explains how the evidence supports the new knowledge claim (Schweingruber, Duschl, & Shouse, 2007). Science values the ability of an unbiased observer to look at the data and draw the same conclusions, as well as clarity of the method to collect data so that others may draw the same conclusions (Manz, 2014). These values which are implicit and shared by all scientists, must be made explicit, practiced, and encouraged in secondary science students.

While it may not be obvious, college lab reports and professional scientific papers have multiple forms of argument embedded in them. For example, the methods section of a lab report or paper makes an unstated claim that the method used is a good one for the investigation (Wolfe, 2011). The process to submit a paper to a scientific journal – which typically requires at least two reviews by referees who are experts in their field – is a collaborative act whereby the author defends their process, data analysis, and conclusions, potentially over multiple revisions, due to contestations in comments of the referee. Therefore, a program which engages secondary science students in the practices of a scientific community is incomplete without argumentation.

The right environment needs to exist for students to successfully engage in argumentation. Students and teachers can be afraid of engaging in argumentation; in our daily life, arguing is seen as combative with a primary goal of "winning." In the secondary science classroom and scientific community, the goal is not to "win" but rather to further everyone's understanding by posing and evaluating claims on the merits of evidence and logic. For this reason, a specific type of classroom community must be cultivated in order to best support argumentation (Olitzky, 2007), such as a student-centered, collaborative environment (Donnelly, McGarr & O'Reilly, 2014; Nielsen, 2013). The theoretical support for a student-centered collaborative classroom culture can also be found in research supporting cooperative learning (Johnson & Johnson, 1986), social interdependence theory (Johnson & Johnson, 2009), as well as the social-constructivist theory of learning (Schweingruber, et al., 2007).

However, a student-centered, collaborative classroom environment conducive to productive argumentation is not easy to establish or maintain. Students need to be willing and able to engage in argumentation (Bathgate, Crowell, Schunn, Cannady, & Dorph, 2015) which requires the direct instruction of argumentation as well as the deliberate creation of a comfortable classroom community. This environment requires careful planning and training of students in the norms of argumentation (Manz, 2014). Manz (2014) describes that a scientific community conducive to argumentation requires opportunities for interaction, involves critique, and includes different perspectives in a way that honors public standards (norms and values) that help build collective knowledge. The classroom has different structures and goals than the scientific community. Thus the classroom environment, tasks, and participation structures play key roles in students' engagement in argumentation. Classrooms that support argumentation focus on *finding something ou*t and *reaching a consensus*; ultimately they are a dialogic knowledge building community in which students construct and critique ideas (Manz, 2014).

The norms of argumentation are complemented by students having shared norms of scientific reasoning (NGSS Lead States, 2013; Choi, Hand, & Norton-Meier, 2014). Inquiry based science education (IBSE) is one example of an instructional approach that aids in the explicit teaching of these norms. In order for students to engage in inquiry, they need training in the cognitive approaches of science: how to create a researchable question, design and conduct appropriate investigations, and use evidence to persuade (Sandoval & Reiser, 2004). In order to support students in IBSE, Choi, et al. (2014) define the following classroom norms of scientific argumentation: arguments are *based on data* sets including the use of diagrams, figures, and other data representations; *logical connections* are drawn between data, evidence, and claims; and observations are clearly distinct from but connected to *interpretations*. With shared, explicit norms for arguments such as these, students know what is required for a robust argument, and can be comfortable holding others arguments to these expectations without feeling the risk of offending the person. Norms like these provide a framework for an argument around ideas, not individuals.

Within a classroom culture with clear norms, the teacher can frame the goals of argumentation in different ways which have a profound influence on the way students engage in the use of evidence and conceptual reasoning (Berland & Reiser, 2009; Garcia-Milla, Gilabert, Erduran, & Felton, 2013; Shemwell & Furtak, 2010). Berland & Reiser (2009) identify three distinct goals of argumentation: sense-making, articulation, and persuasion. They find persuasion to be the most difficult form of argumentation. Placing emphasis on the goal of persuading a general, neutral audience supports students in differentiating between evidence and inferences in their written arguments (Berland & Reiser, 2009). The goal of argumentation must be carefully articulated as it does not always produce discussion focused on probing and refining conceptual ideas that teachers intend. Shemwell & Furtak (2010) find that the strict goal of "argumentation" leads students to use less conceptual reasoning to support claims as it emphasizes the use of empirical data to support a claim but fails to emphasize the importance of explaining the physical reasons why the claim makes sense. A strict emphasis on empirical data based argumentation also limits students' use of other forms of data such as preconceptions, anecdotes, analogies, and insights which are important for furthering student thinking and causing conceptual change. Listening, considering other sources of evidence, and others' ideas is key to the deep learning that comes through collaborative discussion and argumentation. Garcia-Milla et al. (2013) advocate for the use of the goal of consensus (or coalescent argumentation) as opposed to the goal of persuasion in order to support students' understanding through forcing the consideration of counter-claims and rebuttals to their argument.

Embedding Argumentation in Complex Tasks

As previously described, argumentation is a key activity of science and is embedded in the process of knowing. Choosing an activity that lends itself to constructing and defending a scientific argument motivates and enables students to engage in sense-making. In this way, authentic argumentation arises from students investigating a question or phenomenon and seeking to communicate their understanding to others. Presenting students with interesting complex tasks, activities and experiences about which they can inquire and debate is critical to the teaching of argumentation (Sampson, et al., 2013; Berland & Reiser, 2009; Choi, et al., 2014; Hand & Keys, 1999).

Student-driven inquiry provides a natural starting point for argumentation (Sandoval & Reiser, 2004; Donnelly, et al., 2014; Choi, et al., 2014). The Argument Driven Inquiry (ADI) instructional model of Sampson, et al. (2013) outlines a structured authentic inquiry experience which they show bolsters students' understanding of the content, the practice of science, and how to clearly communicate their process in writing. The ADI model asks students to engage in an eight step process where students identify a question in the topic of study (1), collect (2) and analyze data (3) in order to answer the question, and use the data to develop a tentative argument (4). After this initial inquiry process, groups review each other's procedures, data analysis, and conclusions (5) in order to provide guidance to help strengthen their argument, such as suggesting they collect additional data. Individual students then craft their own investigation report (6) which they will revise (8) after it is reviewed anonymously by two peers (7). Upon completion of the report, the teacher guides a whole class reflection on the content, nature of scientific inquiry, and steps to improve future investigations. They find that in order,

> "to improve secondary students' science-specific argumentative writing skills, **<u>and</u>** understanding of the content at the same time, the writing students do during school science laboratories needs to be more **authentic and educative**. To be more authentic, the writing tasks need to be *realistic*, *embedded into the inquiry process*, and *engage students* in the *serious writing* practices of science." (pg. 666, emphasis added)

Argumentation is a complex endeavor, requiring high level thinking and communication skills to ultimately refine ideas and reach an evidence based, conceptually backed consensus. For this reason, argumentation must be embedded in an engaging, authentic, complex investigation which necessitates collaboration and discourse.

Structures and Scaffolds to Support Argumentation

With a classroom community conducive to scientific practice and an engaging and authentic opportunity to engage in argumentation, students still struggle with producing high quality arguments which include explicit connections between claims and evidence, conceptual backings for their claims, and discussion of counterclaims (Ford, 2012; Berland & Reiser, 2009; Falk, Andrew & Brodsky, 2014; Sandoval & Reiser, 2004; Shemwell & Furtak, 2010). From his review of literature, Ford (2012) found science places a unique emphasis on empirical evidence. The use empirical evidence in science is complex and multifaceted: scientists must consider the significance, credibility, and uncertainty associated with any data collection procedure. Different contexts of scientific practice require different ways of constructing argument and connecting evidence to claim. Support can be found through the explicit teaching of what is required of an argument, such as through specific argument structures which define the important pieces required of a robust argument.

Specific Argumentation Structures

There are a variety of argumentation structures which are utilized to construct arguments within science and other academic contexts. Popular at the elementary level and early secondary settings is the Predict-Observe-Explain structure (POE;

Shemwell & Furtak, 2010; Furtak & Ruiz-Primo, 2008). POE is best used with a discrepant event or prescribed investigation where students are introduced to a procedure, they make a prediction of what will happen, conduct the procedure, document observations, and are asked to explain the reasons for why what they observerd happened. While POE is not exactly an inquiry framework, it has a lot of power to support students in making sense of their observations through connections to conceptual understandings in the "Explain" component.

One canonical cross-disciplinary argumentation structure is the Toulmin model (1958/2003) of claims, grounds, warrants, backings and rebuttals. Dunac & Demir (2013) utilize this structure to analyze simple student arguments that students construct when playing a card game, similar to UNO, where they have to make a case for a set of cards representing a complete energy transformation. Each of the Toulmin model components are described below with an examples in the context of the Energy Transformation card game:

- **Claim** – assertion put forward for acceptance, *e.g.* "I have an energy transformation set."
- **Grounds** – evidence to support claim, *e.g.* specific cards that make up energy transformation set (Battery, Light Bulb, electrical energy, radiant energy)
- **Warrants** – explicit explanation of why/how those energy cards relate to the image card, *e.g*. "Electrons move from the battery through the filament in the light bulb causing it light it up. This shows electrical energy transforming into radiant energy."

- **Backings** – generalizations or references to the other experiences of the members to support the validity of this claim, *e.g*. “When we completed the circuit we made in class with a battery, the light lit up, but when the switch broke the circuit, it went out.”
- **Rebuttal/Counterclaim** – exception or limitation of the argument brought up by others, *e.g*. “We didn’t have a battery when we used the hand crank but the light bulb still lit up.”

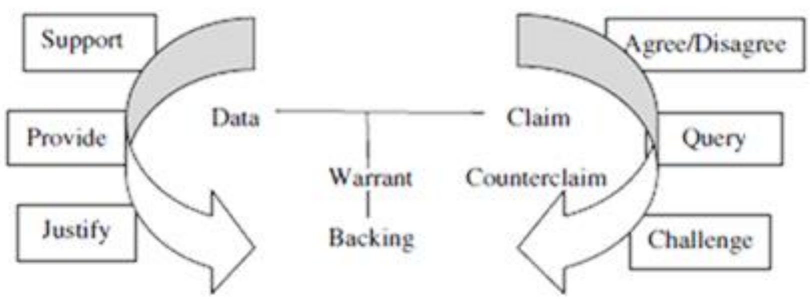


Figure 1 - Argument components and the processes of argumentation (Choi, et al. 2014)

Choi, et al. (2014) utilize this structure to analyze their students’ arguments (Figure 1). They explain the need for warrants and backing because “data do not speak but rather the investigator is required to create a reasoned link between the relevant data and the proposed claim.” (p. 273). Some, including Ford (2012), have taken issue with Toulmin’s argumentation structure as it ignores the interactive, discursive components are argumentation, and instead provides a structure for presenting arguments in a finalized static form. Furthermore, the Toulmin structure is a theoretical framework intended to be an academic tool to decompose arguments and analyze their robustness. While it is useful for an academic analysis of students’ arguments, the Toulmin model is not intended to be taught to secondary students for the purposes of supporting them in structuring their own arguments and critiquing others' arguments.

Other argumentation structures take the complexity of the Toulmin argument pattern and simplify it in a way that it can be easily understood and utilized by students. One such argumentation structure is the Claim-Evidence-Reasoning framework (McNeill & Pimentel 2010; Berland & Reiser, 2009). This simple three component framework consists of

Claim – a statement that provides the answer to the investigation question

Evidence – specific information, observations, or data which support the claim

Reasoning – a justification that explicitly and logically connects the data as evidence to support the claim.

This is the primary argumentation structure utilized in the ADI model which has students repeatedly use this structure to construct their arguments from their authentic inquiry investigations, as well as critique other students' arguments. In their study, Sampson, et al. (2013) found significant improvement in students' content scores, as well as their argumentative scientific writing scores. This improvement was measured according to a standards-aligned content and argumentation assessment given at the start of the year, mid-year and at the end of the year. The continued use of this structure for their investigation reports, and the process of peer review, revision and reflection has great power in supporting students' written argumentation.

Scaffolds & Instructional Practices to Support Argumentation

Structures and scaffolds, such as repeated procedures like CER and common checklists or rubrics for evaluating explanations, are useful for broadly supporting student argumentation in science. However, in the context of specific complex scientific concepts, some argue that students' epistemic understanding of scientific inquiry is best supported by content-specific argument scaffolds rather than broad argument structures. These content-specific scaffolds provide explicit prompts to help address specific supporting pieces to an explanation such as sub-questions, counter arguments (Sandoval & Reiser, 2004). Sandoval & Reiser (2004) use an online argumentation scaffold they created called ExplanationConstructor which provides "Explanation Guides" or scaffolds for explanations that are specific to the online investigation environments. These guides help students focus on the goals of their investigations and help students design and execute investigations which focus on those explanatory goals. Sandoval & Reiser (2004)'s research demonstrated that the tool helped the group focus on whether they had answered the current question with a complete explanation, as well as determine what evidence they had, and what evidence they still needed. The program also aided students in critiquing each other's explanations and revising their own explanations. Online context specific scaffolds, such as this, support classroom norms for argumentation, by ensuring proper evidence is specifically connected to the claim and explained with a conceptual causal understanding of the scientific content.

Other practices in the classroom work to support and refine individual student's arguments as well. Direct teaching of logical reasoning is needed to help students connect big conceptual ideas to evidence (Falk, Andrew, & Brodsky, 2014).

Clear logical reasoning must be explicitly taught in order for students to construct robust scientific explanations, especially with the CER framework. Different situations call for different reasoning, but some prominent examples of reasoning students will use in science include deductive, inductive correlative and inductive causal reasoning. *Deductive reasoning* applies general principles to specific situations to draw a conclusion about that situation. *Inductive correlative reasoning* is when researchers report trends (positive or negative) between two variables. *Inductive casual reasoning* identifies differences in one variable due to the presence or absence of another variable thereby inferring a causal relationship between the two (Falk, et al., 2014). Strong arguments in science are causal and deductive rather than correlative.

These logical conclusions and arguments are supported through evaluation and feedback from peers and instructors. When students get constructive feedback, they gain a clearer understanding of how to explain and convince others; the collaborative aspect of argumentation is crucial. Some ways students collaboratively support each other's individual arguments is through written peer review (Ford, 2012; Sampson, et al., 2013), and through a variety of forms of collaborative discourse (Chen, Hand, & McDowell, 2013; Berland & Reiser, 2009; Nielsen, 2013; Ford, 2012).

Discourse and Argumentation

The nature of argumentation involves discourse: *dialogic interaction* with different ideas and determining the relationships between these ideas. Scholarly discussions of argumentation often involve specific treatment of the dialectical features of argumentative dialogue. Dialectical features of argumentation are the features that students use to engage with each other's ideas and manage disagreement between ideas (Nielsen, 2013). This contrasts with the features of argumentation outlined by Toulmin (1958/2003) (i.e. claim, evidence, warrant, backing, rebuttal) which provide a structure for analysis of the logical patterns of a static argument product. Dialectical features of argumentation can be thought of as the responses to a Toulmin style argument; these are what make argumentation a process which is dynamic and responsive, thus allowing for collaborative learning. Examples of dialectical argumentation moves are questioning, requesting justification, elaborating, and anticipating others reactions (Nielsen, 2013). These features can be identified objectively through specific words or phrases that serve as argumentative indicators, such as "because," "since," "as," "so," "therefore," "but," and "I disagree." (Erduran, Simon, & Osbourne, 2004). These phrases require interaction between claims and evidence when an argument is initially posed, as well as engagement with ideas another has offered in response to the argument. While the dialogic nature of argumentation is the same, argumentation in secondary classrooms takes the form of both written and verbal discourse.

Argumentative discourse involves written and spoken discussion (Berland & Reiser 2009). These two work hand in hand; preliminary writing of an individual's thoughts supports their participation and the whole group's discussion, just as participation in group discussion supports the quality of an individual's summative written argument (Anderson, Zuiker, Taasoobshirazi & Hickey, 2007; Chen, et al., 2013). Argumentative discourse can occur in many setting in the secondary classroom, such as between two students, in small groups, or with the entire class. Each of these instances is supported by the classroom teacher in a myriad of ways: through the scientific community and norms established, the task and participation structure chosen, and the deliberate decisions they make in regard to their direct role in the discourse.

Teacher's Role in Discourse

The practice of initiate-respond-evaluate (IRE), often used by teachers in traditional classrooms, shuts down the process of collaboratively engaging in explanation and argumentation between students. The teacher is the center and main authority in the IRE model, asking a question to a student, who responds, and the teacher evaluates that response. In this model, the knowledge or answer is either confirmed or denied by the teacher, so even if there was some discussion between students it usually ends with calling the teacher over to see who was right. Discursive argumentation disrupts this pattern, and shares authority between all members of the classroom. Berland & Reiser (2009) advocate for students to engage in a collaborative dialogue, sharing, questioning and defending explanations. This requires the role of the teacher to change in the classroom; it provides a need for the teacher to release some authority and delegate it to the students. This redistribution of authority is difficult to accomplish from both the teacher's perspective and the students'. Teachers have seen few examples of collaborative, student-centered classroom, in their own schooling or in their teacher training programs. Students are conditioned to look to the teacher as an authority on the subject whose role is to answer their questions. These complex power relations make the collaborative discourse necessary for argumentation difficult to accomplish. In studies of teachers' attempts to implement student-centered inquiry activities, researchers have found that teachers' ways of facilitating student-student discourse can significantly add to or detract from students small group discussion and therefore their collective understanding (Donnelly, et al., 2014; Anderson, et al., 2007).

The dynamics of power between teacher and students in IBSE laboratory setting were studied in Irish secondary science classrooms by Donnelly, et al. (2013). The researchers conducted an indepth study of the interactions of two Irish teachers who engaged their students in IBSE by conducting inquiry using a Virtual Lab. In this study, the researchers noticed the direct power techniques of surveillance and distribution (ensuring resources) were used by both teachers. Both teachers primarily initiated student interaction for surveillance, though they did so in different ways. One teacher's questions were answered in a way that suggested the students thought the teacher was monitoring for <u>progress</u>, while the other teacher's students' responses suggested that the students' thought the teacher was monitoring for <u>understanding</u>. This surveillance sends powerful messages to students, such as the expectations for what should be achieved. These direct power techniques can shift the ownership back to the teacher despite the student ownership emphasized in IBSE.

Donnelly, et al. (2013) also noticed indirect power techniques of norm-defining, ownership of ideas, and persuasive discourse. Norm-defining was prevalent in the discourse in order to ensure students understood the task, expectations and could complete it within the allotted time frame. Students looked to the teachers to specify procedural norms even though the IBSE nature of the task directed them to determine the procedure. Due to time constraints, the teachers often provided support to help students with procedural norms. Students in this study resisted or demonstrated through their speech that they were uncomfortable with the new found ownership they had over experimental design in IBSE. However, based on the student interview data, there were different opinions on ownership among students: some found the inquiry based Virtual Lab liberating as they could easily and quickly experiment. The main dialogic pattern they found in these teachers' persuasive discourse power relations was a Socratic dialogue of guiding questions. The typical pattern was teacher-dominated, and based on transcripts it was not clear from their research if this dialogue affected student understanding of content.

While it can be difficult to share power with students, one key collaborative role the teacher can play is that of a facilitator, especially in supporting whole class discussions through the use of open ended questioning (McNeill & Pimintel, 2010). Based on analysis of the amount and type of teacher questions in whole class discussion, McNeill & Pimintel (2010) suggest that one teacher's use of open ended questions encouraged more students to engage, their use of persuasive language to support claims with evidence and reasoning, and more student-student interactions.

Written Argumentation

Scientific literacy is the ability of students to "read and write texts, connect different language systems, and construct the components of a scientific argument" (Chen, et al., 2013). Writing provides an important lens into an individual students understanding of content as well as their understanding of the structure and function of argumentation in constructing scientific explanations. As discussed previously, there are many ways to engage students in the scientific process of argumentation, however writing provides a unique window for assessing an individual's understanding of the concepts and nature of science, in formative or summative way. However, *the practice of argumentation* itself is a part of the content for many disciplines. So, in addition to using argumentative writing as a tool for learning concepts, it can also be a tool to assess students' ability to construct, analyze, and critique arguments.

Discursive Writing to Build Knowledge

Chen, et al. (2013) conducted a study where teachers engaged elementary and secondary school students in persuasive correspondence to determine the effect it had on students' conceptual understanding of specific scientific content. The 4th grade students collaboratively wrote letters to 11th graders about force and motion. Their letters were structured with the argument style of Question, Claim, Evidence (an explanation consisting of data and reasoning). The students engaged in collaborative discourse to craft their letters. In this process they could give and receive immediate feedback, hear, discuss and critique various positions, and form a consensus which was then crafted into the letter. They wrote three letters one at the beginning, middle and end of the unit on force and motion. The researchers had this "treatment" group and a control group and looked at their pre- and post-test data for conceptual understanding. Students in the treatment group outperformed students in the control group by a statistically significant margin. The effect size was even more significant for girls, low socioeconomic status students, students with disabilities, and gifted students. Students whose letters had strong relationships between claims and evidence had larger gains in conceptual understanding. This demonstrates how writing can be used to build conceptual content knowledge.

Assessment of Content through Argumentation

Argumentative writing provides an important window into an individual students understanding of the content. Furtak & Ruiz-Primo (2008) studied different types of formative assessment prompts to see which ones solicited the best scientific explanations. They found that open-format written formative assessment prompts elicited a wider range of student ideas and may work best for teachers to provide feedback to advance student understanding. However, more targeted prompts appear to work best for soliciting "scientifically appropriate responses" from whole class discussions. Different formative assessment prompts have different value. Some are better at soliciting students understanding at the appropriate level (e.g. POE). Others are better at getting an idea of the ways students are making meaning with the content (e.g. Constructed Response). The authors advise that "the development of high-quality formative assessment prompts requires a careful review of the unit to be taught." They suggest identifying conceptual "joints" which are key points on the way to learning a concept where written formative assessment is necessary to gauge and solidify student ideas in order to be able to further understanding of the concept.

Assessment of the Practice of Argumentation

As we have established previously, argumentation is now a required process for many disciplines including science. In order to better understand our student's argumentative abilities, and determine the effectiveness of strategies to teach argumentation, there is a need for a way to formally assess argumentation. While there are ways to assess argumentation in the form of verbal discussion in the secondary science classroom (Berland & Reiser, 2009), these methods typically limit the sample size as they involve time consuming transcription and coding of audio or video recordings. Students' written argumentation, while formal and static, is more likely to be used as a standardized way to evaluate instructional practices as well as student's ability to construct argument.

In studies of the writing-intensive instructional model, Argument Driven Inquiry (Sampson, et al., 2013), they advocate for "writing to learn by learning to write" (Carter, Ferzli, & Wiebe, 2007). This involves the use of writing -- grounded in authentic inquiry experiences -- as a vehicle for students to learn both specific content and the practices of science. Their results suggest that the more ADI cycles a student engages in and the more writing, peer review, and revision they engage in, the more students understand in terms of content and complexity of scientific argumentation. In order for Sampson et al. (2013) to determine the effectiveness of this system they designed a written argumentation assessment. This assessment presented students with some background information and a related data table and prompted them to analyze a written argument which has some flaw. The student's response should refute the claim using specific references to the information provided and suggest a counterclaim with specific support from the information provided. This structure provides one possibility for a standardized argumentation assessment.

Different studies have posed different ways to assess and analyze students' written argumentation. Sampson, et al. (2013)'s written assessment of argumentation was scored on a rubric which focused on three features of the argument (1) the structure and complexity of the argument, (2) the quality and relevance of the content of the argument, and (3) the spelling, grammar, and mechanics of the argument. Berland & Reiser (2009) assessed students written argumentation through the lens of how well they achieved each of the three goals of argumentation *sense-making* of phenomena, *articulation* of ideas, and *persuasion* using explicit connections between claims and evidence. Erduran, et al. (2004) provide 5 levels with which to characterize static written arguments according to their sophistication or complexity. A *first level* argument makes a claim, to move it to the *second level* the argument supplies evidence for the claim. The *third level* argument involves at least some clear connection between the data and the claim. A rebuttal or counter argument which provides a strong and clear connection between the data and the claim is included in a *level four* argument, and more than one rebuttal is discussed in a level five argument. In Erduran et al. (2004)'s structure, level four and five have clear and apparent dialogical features of the interaction between the authors claim and others ideas and arguments.

The use of writing in the secondary classroom is crucial to helping student make sense of content as well as helping teachers understand their students' thinking. Writing provides an opportunity for students to formalize their ideas – which they may have arrived at through discourse – in a logical way for others to review and critique. The assessment of individual student's written argumentation is necessary tool to evaluate a student's ability to construct an argument, as well as evaluate the success of instructional strategies intended to teach argumentation.

Conclusion

Argumentation is a critical goal of today's schools as a way to develop rational citizens who can critique the validity claims about phenomenon in society and the natural world. Additionally, argumentation supports education's goal of producing citizens who can analyze new situations and present arguments that further the knowledge of society. Arguments are used by society to confirm and clarify theory as well as decide on the best plan of action. The NGSS (NGSS Lead States, 2013) present argumentation as a key component of the scientific process of answering a question, as well as the engineering process of deciding between different possible solutions to a problem. By engaging in the practice of argumentation, students engage in the process of science, which inherently involves the exchange of ideas and response to others critique of these ideas. This discursive nature of argumentation requires students to collaborate in the construction of knowledge, which is shown to produce significant gains in students' understanding of scientific content (Sampson, et al., 2009). Fostering a classroom environment that is ripe for the co-construction of knowledge is a difficult task, which requires deliberate, explicit shift in classroom culture toward one where students share authority with the teacher and work together with the intent to co-construct knowledge. While argumentation is a discursive process, the individual written argument produced by a student allows educators a window with which to evaluate conceptual understanding of science content as well as their ability to construct a robust argument. Therefore, written argumentation must be a critical feature of future research in the use of argumentation and teaching of argumentation in secondary science education.

Chapter III: Methods

In this section, the previously discussed research is put into practice in a secondary STEM classroom (namely, a high school physics classroom). Specifically, we investigate the impact of three specific strategies,

1) a clear argumentation structure (CER)
2) collaborative discourse to engage in argumentation and provide feedback
3) embedding argumentation in an inquiry task

on the strength of students' written arguments.

Overview of Methods

The methods consist of three rounds of argumentation assessment:

Round 1) Baseline of argumentation (laboratory report)

Round 2) Direct teaching, guided practice, and partner practice in a guided inquiry task

Round 3) Argument driven inquiry investigation

These are content driven argumentation tasks which asks students to explain their data using physical reasoning. Between each of the rounds the teacher researcher assessed each student's work for content and were coded to track the strength of student reasoning in their arguments, similar to how Bathgate, et al. (2015) analyzed students' justification for their claims. In this study, this researcher looked for arguments which use a clear claim, specific reference to evidence, and three levels of logical reasoning: no reasoning, limited reasoning, and physical reasoning logically connecting evidence and claim. This analysis simplifies Bathgate, et al. (2015)'s six levels of argument into a coding of 1 to 3 which focus on the student's reasoning (see Table 1 for examples of coding).

Population

The 57 students in this study are part of a large northeastern US suburban school district. The students are in grade 10 (n = 2), 11 (n = 20), and 12 (n = 25) and taking New York State's Regents Physics course instructed by the author. Not all students completed each assignment at the time of data analysis, therefore the sample size for each analysis varies.

Table 1 - Reasoning coding rubric with example responses

Coding Criteria	Example Student Response – Round 1
1 – *no reasoning*	"On part two, our runner ran with constant acceleration."
2 – *limited reasoning* (e.g. data meets expectation, no explanation of expectation)	"Yes the runner did move with constant velocity because the best fit line hits most of our data points."
3 – *physical reasoning logically connecting evidence to claim*	"My runner did move with constant velocity. According to the distance vs. time graph there is a direct relationship shown. The velocity remained constant. This makes sense because constant velocity means that something is moving along a straight line, as every second of times goes by, the object travels through some number of meters. It travels equal displacements in equal time intervals."

Round 1: Baseline of Argumentation

In order to probe students' initial abilities to construct arguments, the students were prompted to use data collected in a typical laboratory to argue as to whether or not the two types of motion studied represented (1) constant velocity and/or (2) constant acceleration. Students were given the following prompt:

"Make an argument, using your data, for each of these questions:

A. Did your runner move with constant velocity in part 1?

B. Did your runner move with a constant acceleration in part 2?

(Your argument should have a Claim, specific reference to Evidence and Reasoning to connect your evidence to your claim.)"

The students had no explicit introduction to the terms Claim, Evidence and Reasoning. Students had not previously used this argumentation structure in science. However, the district's writing handbook uses the terms claim, evidence, and interpretation as a structure to support evidence based writing in English language arts classes. None of the 3 strategies studied in this action-research were used to support students writing in this task.

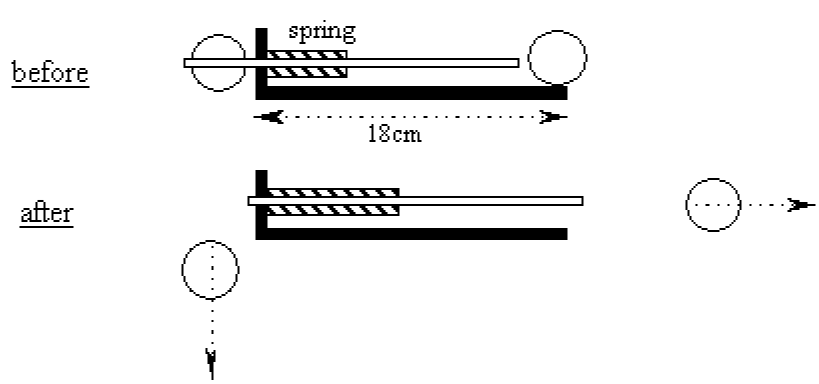
As part of the course structure, lab reports which did not demonstrate mastery of the learning objective of the lab, required revision and resubmission to earn credit. 37 out of 46 (76.5%) of labs were returned to students for revision for a variety of reasons. Because of this, some students were given the additional support of feedback and revision to strengthen their baseline arguments.

Round 2: Guided Inquiry

In this round, we introduce the supports of direct teaching and modeling of the Claim-Evidence-Reasoning structure as well as practice with the CER structure embedded in a guided inquiry task. The teacher-researcher framed the lesson around the idea that science is a social endeavor, scientific findings need to be shared and reviewed by others to be vetted, put under scrutiny, and ultimately discussed as a contribution to science. Students took notes on the definitions of each part of the argument and analyzed in pairs 4 physical science arguments of increasing complexity, with the final argument a direct quotation from a students revised conclusion from the base line assessment (see handout in Appendix A).

Task: Upon conclusion of this teaching and review of the arguments, students were given an inquiry task where they needed to collect data in order to craft their argument. The structure of the classroom has students at tables in pairs. Nearby pairs were combined into collaborative groups of 3 or 4 students to plan and conduct the investigation. The context of this argument was a classic and engaging physics question: which ball will hit the ground first, one shot horizontally off of the top of a cliff or one dropped at the exact same time.

Figure 2- Demonstration Apparatus for Round 2 argument (Harvard University)



Groups were provided with and shown how to use equipment which allowed them to replicate this exact problem (Figure 2). From there, groups created their own procedure and chose what data to collect to analyze the problem. Some groups chose to time each ball's fall; other groups chose to use their phones to record a real time or slow motion video of the fall of each ball. Upon data collection, each student wrote their own argument in a claim-evidence-reasoning structure, with a prompt to clearly indicate each piece.

These arguments were then reviewed by the researcher and coded according to the same criteria as in round 1. Based on the arguments seen, the researcher expanded category 2 in also include incorrect reasoning, as reasoning was present but did not appropriately use evidence to support the claim. Examples of arguments from round 2 can be found in Table 2.

Table 2 - Example Student Responses - Round 2

Coding Criteria	Example Student Response – Round 2
1 – *no reasoning*	"We believe that both balls, one dropped straight down and one shot out the side, will land at the same time. After dropping the ball straight down the first time, we recorded a time of .45 seconds. After the second drop of the ball straight down we recorded 0.49 seconds. Then we recorded the time it took for the ball to land being shot out from the side and timed 0.45 and 0.49 seconds for the second trial. This shows that it takes the balls the same amount of time to drop."
2 – *limited reasoning* (e.g. data meets expectation but no explanation of expectation) *or incorrect reasoning*	"The ball that fell straight down landed before the ball that was shot. Our group took a slow motion video and when we viewed the video we saw that the ball that fell straight down hit the table before the ball that shot out. This is because one of the balls had a hole in it while the other did not which affected the air resistance." (no coding)

3 – *physical reasoning logically connecting evidence to claim*	"The two metal balls hit the ground at the same time. According to the video, one can see and even hear the balls bouncing against the floor at the same time. This makes sense because the acceleration of Earth's gravity, which is pulling on the balls is the same acceleration of 9.81 m/s^2. This means that they would hit the ground at the same time because the acceleration is the same. They also fell from the same height, so combined with the acceleration, it means that the balls would hit the ground at the same time."

As discussed in chapter 1, an engaging and inquiry based tasks supports students' argumentation as they are more willing to engage in these tasks (Bathgate et al., 2015; Berland & Reiser, 2009). Also, this question was chosen as it highlights a well-known conceptual hurdle for student and is therefore worth taking the time to explore, discuss, and have students write about to demonstrate their conceptual understanding. As students demonstrated a lack of skill with using physical reasoning to explain patterns in data, this task was ideal as the reasoning involved to explain this scenario is challenging but approachable at this point in the course. Furthermore, even if students' data pointed them towards an incorrect answer to the problem, they can still employ logical physical reasoning to explain their outcome. There is certainly a risk in this activity because, should students collect data that shows the incorrect answer, it could affirm the misconception.

Round 3: Argument Driven Inquiry

In this next round of inquiry based argumentation, we introduce the ADI approach to support students written arguments (Sampson et al., 2003; discussed previously). In addition to the ADI approach which is rich in discourse, the researcher introduced the scaffold of a whole class discussion of data in a structured online environment (Sandoval & Reiser, 2004), prior to drafting of the initial lab report. The researcher also made formative instructional decision to engage the class in a teacher lead whole group discussion upon observations of students' discussion after the peer review of their initial lab report.

Task: Students were tasked with investigating what factors would cause a projectile to go the farthest horizontal distance (Appendix B). I introduced the laboratory investigation by asking students to walk me through how to play Angry Birds (a ubiquitous projectile problem). Students worked with their partners to form a specific investigation question (e.g. how does angle of launch affect the range of a projectile), and make a hypothesis as to what would produce the longest range. After grouping pairs into groups of four who choose to study the same question, I demonstrated the use of some new equipment available which they could use to investigate their group's question, namely marble launchers and photogate timers.

With their group students collaboratively wrote a procedure and collected their data in one 45-minute class period. The following day they had time in the computer lab to graph and analyze data. The students engaged in an online discussion of their results on a platform called Schoology with the discussion prompt for "one person from each group to share their results" as well as "Use this space to ask any questions you have about the investigation or interpretation of the results." The final written laboratory reports were due four class days later, where students were told they would be reviewing each other's work.

Peer Review: Using a clear structure of criterion for success based checklist (Appendix C), students silently reviewed each other's initial investigation reports.

There were directed to clearly indicate where they did (or did not) find their claim, evidence, and reasoning, and gave their peer written comments. Upon the completion of this independent review, students verbally discussed the report and went through any changes that needed to be made. During the partner review the researcher, as well as an instructional coach in the district too notes on student's engagement in the task. Based on observations in this partner review, the researcher decided to initial a whole class discussion of the data as well. Following this guided peer review and whole class discussion, students had four class days to submit their final revised investigation report.

The conclusion section of their investigation report was used as the data for this analysis. Examples of student arguments for each criteria are found in Table 3.

Table 3 - Example Student arguments around the effect of angle on how far a projectile will travel

Coding Criteria	Example Student Response – Round 3
1 – *no reasoning*	"Through this lab I learned that the best angle to use when wanting the optimal horizontal distance is 45 degrees. As you increase Vi, the range, the distance in the x-direction, also increases. By looking at the data 45 degrees is the peak and anything more or less would be less distance in the x-axis."
2 – *limited reasoning* *or* *incorrect reasoning* (examples provided in Chapter IV round 3)	"Different angles will alter the distance the ball travels, angles closer to 45 degrees will allow the ball to travel far, and angled at 45 degrees the ball will travel farthest. This is evidence in the table and the graph above, where 30 degrees allows for 2.8 meters of distance traveled and 60 degrees allows for 3.1 meters of distance traveled. At the angle 45 degrees the farthest distance traveled is 4 meters. I believe this to be true because when a ball is kicked directly up in the air at 90 degrees the ball returns straight down and does not

	usually travel much distance. Similarly, when a ball is kicked at 45 degrees, it travels farther than it would at any other angle.”
3 – *physical reasoning logically connecting evidence to claim*	“From this experiment it can be concluded that the closer the initial angle is to 45 degrees, the farther the object will travel. 45 degrees can be considered the optimum degree in order to launch something as far as possible. When the angles are closer to 0 or 90 degrees the ball didn’t even travel farther than 0.2 meters. When the launcher was set to 45 degrees, the object made it 4 meters! The reason why this is true is because if the angle to too narrow or horizontal, there is not enough air underneath it to allow it to move anywhere. If the angle is too steep or vertical, there is little to no forward velocity so the object will barely move away from where it was shot. 45 degree is the ideal angle because it allows for forward velocity and air underneath to allowing it to travel a far distance.”

Chapter IV: Analysis

The initial sample of arguments showed that the students could interpret evidence to create strong claims and explicitly provide the appropriate evidence to support their claims (specific examples in Table 1, aggregate results in Table 4). However, few students included reasoning in their initial arguments. Any reasoning included was not sophisticated and mainly referred to how the data did not meet the expected trend in the data.

Table 4 - Results of Coding of Students Arguments

Level of Reasoning	Baseline (n = 46)	Round 2 (n = 51)	Round 3 (n = 42)
1 – no reasoning	16 (34.8%)	10 (19.6%)	3 (7.1%)

2 – limited or incorrect reasoning	15 (32.6%)	1 (2.0%)	22 (52.4%)
3 – strong reasoning	15 (32.6%)	40 (78.4%)	17 (40.5%)

In the second round of argumentation which involved direct teaching, guided partner practice and argumentation embedded in a group inquiry activity, there was a significant increase in the percentage of students demonstrating the highest level of reasoning, that which is clearly and logically explaining why the claim is true. (Examples in Table 2, aggregate results in Table 4). While students demonstrated great improvement in their ability to provide reasoning, it is hard to tell which of the new strategies was most effective in producing this result: the inquiry based nature of the task, the group based nature of the task, or the direct teaching of the CER structure.

Much of the work in the class is done in partnerships or groups, so while working in groups was a new support *for argumentation* it was not a new strategy to support *student's content based discourse*. In terms of levels of inquiry, the inquiry students engaged in was largely guided as the teacher provided the question and equipment but tasked students with collecting and interpreting their own data. The most significant change in this round was the introduction and emphasis on the CER argumentation structure. Because of this, the results of this round can be largely attributed to the modeling, practice, and use of the CER structure.

The third round of argumentation featured the supports from previous rounds of an inquiry based task, group work, and reference to the CER structure as well as a practiced lab report structure. New strategies introduced to support argumentation included embedding it in an open inquiry task, structured discussion of results in an online space, structured peer review of initial arguments, whole class discussion of merits of different examples of reasoning, and revision from targeted feedback.

ADI Elements: Open Inquiry, Peer Review, and Revision

As seen in Sampson, et al. (2013), the open ended nature of this inquiry task lead to greater student engagement in the task and more thoughtful, reasoned arguments. Further evidence of this comes from students' laboratory reports which featured rich connections between the factors studied in the experiment and the experiences in their daily lives. Also, the student driven nature of the experiment was evident in the level of detail in students' procedures. Compared to previous laboratory reports where the procedure was given, this laboratory report featured more complete procedures with students correctly identifying all required equipment and its use in their procedure.

Observations during the structured peer review indicate that students were deeply engaged in each other's work. Students actively used the peer review checklist structure to support each other. Students were also observed to have taken out their laboratory report grading rubrics to help support their peers in improving their lab reports. Students communicated with each other in productive and supportive ways, saying things like "I know what you're saying here, but just try again so it's easier for me to understand the relationship." and "Compare the two extremes instead of just talking about one."

Whole Class Discourse

From analysis of students' peer review checklists, the reasoning was missing from most student's initial arguments. Of the 30 peer review checklists submitted with their revised assignment, 23 of them indicated that at least some amount of reasoning should be added to strengthen their written conclusion. From observations of different types of reasoning during the peer review phase, the researcher decided to initiate a whole class discussion using the planned open ended questions (McNeill & Pimentel, 2010) of

- What reasoning did you find in your partner's work?
- What are the strengths of this reasoning?
- How could this reasoning be improved?

The class examined examples provided by students, and made specific suggestions to strengthen their explanation of why a 45 degree angle would produce the longest range. For example, one student discussed the extreme case of 90 degrees and how that would not produce a long range because the projectile would just go straight up into the air and fall right back onto where it was launched. Students suggested this response could be strengthened by also discussing the other extreme, 0 degrees, and why that also would not produce a long range. Adding the other case provides a much needed step towards supporting the middle angle, 45 degrees, as the one that produces the longest range.

Results

With the additional supports of the structured peer review and the whole class discussion with open-ended questions, students produced arguments with more than 90% of them featuring limited or strong reasoning. 40.5% wrote arguments whose reasoning fell in the highest level of strong correct physical reasoning, logically connecting the evidence to the claim. (Examples of student reasoning are found in Table 3).

In this round, we do see a greater number of responses falling into the limited or incorrect reasoning category. This may have to do with the open-ended nature of the task and the complexity of the reasoning required for the task. The previous two rounds dealt with one dimensional motion and only required simple reasoning focused around a narrow topic. As this task was an open ended complex problem involving motion in two dimensions, there are a lot of factors that students may have interpreted as important to the explanation which in fact are not. Some incorrect factors students identified and discussed as reasoning for their results were "a changing acceleration due to gravity," "more tension," "more friction causing the ball to stay in the air longer and go farther." Even though this task was open-ended and the most complex in terms of the reasoning required, it showed the largest number of students using some form of physical reasoning in their argument.

Chapter V: Discussion

Current education literature and this practitioner research suggest the following strategies have a positive effect on students' written argumentation:

1) Direct teaching of argumentation structure

2) Collaborative discourse to engage in argumentation and provide feedback
3) Engaging, inquiry based tasks

While the sample size of this study is not large enough to make any substantial claims, we can still take away some lessons from the use of these structure and suggest directions of future research in these three areas.

Argumentation Structure

Direct teaching of the argumentation structure provides clear expectations for students and grounds for specific feedback which students can focus on and refine until they have created a strong evidence based, conceptually reasoned argument. This research supports the use of the CER argumentation structure (McNeill & Pimentel 2010; Berland & Reiser, 2009), in a way that students are taught to understand the structure, given practice identifying parts of the structure, as well as practice using the structure in new content based scenarios. This work primarily looked for structure in the presence of a claim, evidence, and concept based physical reasoning. To continue to support students' arguments, the strength of physical reasoning should also be supported and assessed. Based on the results of this work, future work with argumentation will focus on strategies to strengthen reasoning, such as considering extreme cases, incorrect claims, and counter claims. Also, the identification or development of a structured, detailed, evolving rubric in student friendly language should be a direction of future research to support students in their ability to self-reflect and continuously improve their argumentation abilities.

This research utilized a modified structure of Bathgate et al. (2015) to code student arguments according to their use of reasoning. The work of Erduran, Simon, & Osbourne (2004) identified specific words which show the interaction between ideas required of robust argumentation (namely, “because,” “since,” “as,” “so,” “therefore,” “but,” and “I disagree”). Reviewing student arguments from this study, all of the examples of the highest levels of reasoning featured one or two of these specific indicators of justification in argumentation (namely, “as” and “because”). Also, as the level of reasoning increased, the number of these indicators of justification in their writing also increased. These specific phrases might be useful in developing a rubric to support standardized written argumentation assessment.

Collaborative Discourse

Collaborative discourse can take many forms; this research utilized discussion with a partner, in a small group, with the whole class (teacher-led), as well as online. With discourse comes an authentic audience: someone who will listen to the student’s idea and thoughtfully interpret it for the student’s understanding. This collaborative discourse is one way to make student’s learning public; in this way, student learning is more authentic as it has a true audience who will respond to the student’s ideas to support their learning.

The effect of collaborative discourse is best seen in the third round of argumentation in this work, both in preparing for the peer review and the results of the peer review and whole class discussion. The initial stage of the third round of argumentation showed the greatest completion rate of any of the rounds of argumentation (and any of the initial drafts of their investigation reports all year).

Students knew their arguments would be reviewed by another person on that day of class and their preparedness shows students were motivated by the authentic audience and authentic reason for timely preparation of their initial argument. This peer review and structured whole class discussion afterwards was effective in supporting student arguments as over 90% of students' revised arguments featured limited to strong reasoning.

Support through the use of a structured online discussion space is also seen in the work of Choi, Hand & Norton-Meier (2014) and Sandoval & Reiser (2004). While this research shows online discourse supports students' arguments, the online discussion that took place in this research was a surface level, primarily claim and evidence based. None of the discussion posts extended their argument to the reasoning level. The use of online discussion did not support students' arguments primarily due to the task description, "one person from each group to share their results" as well as "Use this space to ask any questions you have about the investigation or interpretation of the results." The failure of this prompt to elicit conversation further highlights the teacher's role in supporting students' argumentation. The teacher is so influential as they choose appropriate supports and determine the wording of the task in order to support a particular instructional goal. The weak discussion prompt produced the weak argument based online discussion. Even though it was not a successful support in this work, the research presented here does not refute the usefulness of an online discussion platform for engaging students in argument based discourse. Our results serve to further emphasizes the importance of the teacher's role as the choice of prompt is key to the success of student argumentation.

Students will continue to use, practice, and refine their argumentations skills in a variety of disciplines into college and beyond (Wolfe, 2011). The work done here was content-focused, soliciting reasoning in the form of students' understandings of the physical world. Other arguments students engage in will have a more social context where reasoning can be equally as valid and strong without having to have the backing of strong scientific principles. To provide students with practice in both types of reasoning, I plan to engage students in an online argument based discussion around current, engaging, relevant topics such as going to Mars (e.g. Would you go to Mars? Why does humanity even want to go to Mars? Should we colonize and/or terraform Mars?). Whether online or in person, the social aspect of argumentation must remain due to its profound impact on soliciting students' ideas, confronting misconceptions, and refining conceptual understanding.

Engaging Inquiry-based Tasks

As with an online discussion, any task is best executed by students when they are given an engaging task that they can guide their own inquiry into. Choice and student ownership of the task are key engagement pieces that come with relevant, inquiry based science teaching. The inquiry embedded argumentation seen in this work, started out guided and moved to more complex inquiry with choice of question and method of data collection. The improvement in presence and strength of reasoning seen in this research, provides additional support to the dozens of papers which claim students' engagement in argumentation derives primarily from their engagement and interest in what they are arguing about. Given appropriate choice, support in use of equipment, and peers to discuss their results with, students will improve in making strong claims, grounding claims in relevant evidence, and identifying the physical reasoning to justify their claim.

Acknowledgements

This work was supported through course work at the College at Brockport and professional development through the Brighton Central School District's K-12 Science Program Evaluation and the Knowles Science Teaching Foundation. This is an example of the type of work that is done by classroom teachers every day, when they have the time and space to also be engaged in quality relevant teacher-driven coursework and professional development.

Appendix A

DIRECT INSTRUCTION :

Communication (Classroom Norm: Communicate Productively)

- An important part about being a scientist is *communicating* your ideas to others in the scientific community
- By putting your findings "out there" others can…
    - Peer review what you've done, looking for mistakes or factors overlooked
    - Try to replicate your experiment to see if your theory holds true in different situations

Claim-Evidence-Reasoning *(one structure use to communicate experimental results)*

**Claim - ** a statement that answers the original question/problem

**Evidence - ** scientific data or observations that support the claim

**Reasoning - ** justification that connects the evidence to the claim
(usually involves a physical explanation of why claim is true)

STRUCTURED PRACTICE:

In each example below, identify:

- **the *claim* by placing a circle (loop) around it,**
- **the *evidence* by underlining it, and**
- **the *reasoning* by placing a box around it.**

1. Air is matter. We found that the weight of the ball increases each time we pumped more air into it. This shows that air has weight, one of the characteristics of matter.
2. Cold air weighs more than hot air. When I filled a 9 centimeter diameter balloon with cold air it weighed 1 gram and when I weighed the same size balloon with hot air it weighed 0.5 grams. When molecules are cooled they move closer together and when they are heated up they move farther apart. Because of this more molecules can fit into a balloon when the air going in is cold than when the air going in is warm.
3. I believe that the temperature of the water is approximately 100^{o}C. I observed that there were bubbles starting to rise from the bottom of the pan that was sitting on top of a heating element. There were no other substances added to the water that would have caused the bubbles to form. I know that the formation of bubbles is an indication that water is approaching its boiling point. Since I also know that the boiling point of water is 100^{o}C, I am confident that the temperature of the water is approximately 100^{o}C.

PARTNER PRACTICE IN ARGUMENT DRIVEN INQUIRY TASK:

Now, you try!

Write an argument. Make a claim about which ball lands first, support that claim with evidence, and tie it altogether with reasoning.

Make sure to:

- **the *claim* by placing a circle (loop) around it,**
- **the *evidence* by underlining it, and**
- **the *reasoning* by placing a box around it.**

Appendix B

Essential Questions:
What factors influence the range of a projectile?
What effect do they have on the range?

Your Question:

Prediction/Wild Guess:
Describe how you think it will affect the range.

Procedure:

- You will CREATE YOUR OWN procedure and document it on a separate sheet of paper
- Record all data neatly on a separate sheet of paper

However, I suggest that you…

- Use a BOX for the ball to land on so it starts and ends at the same height (maintaining symmetry).

<u>Choice 1:</u> The effect of **launch velocity** on the range of a projectile.

First, we need to know the launch velocity of your launcher at each of the five notch settings. We will do this in a simple way, as this is not the purpose of our lab.

- Measure the time that the diameter of the ball takes to pass through the photogate.
- Use this time it took for the diameter of the ball to pass through the photogate and the ball's diameter (0.019 m) to calculate the initial velocity.

<u>Choice 2:</u> The effect of **launch angle** on the range of a projectile.

<u>Choice 3:</u> Another factor you want to investigate that is not listed above.
Get this APPROVED by Ms. Arnold before pursuing.

<u>For your Lab Report</u>

Introduction : as usual – see rubric

Methods: Only describe what your group did - as usual – see rubric

Data & Analysis: - as usual

- Graph your data with Range on the X-axis. Either…
    1) Range vs. Initial Velocity OR
    2) Range vs. Launch Angle (you do not need to find a line of best fit) OR
    3) Range vs. ??? (factor of choice)

Each group member must have their own graph and description.

Conclusion:

In paragraph form, construct an argument using Claim-Evidence-Reasoning format.

- Make a **claim** addressing the essential questions
- Provide the **evidence** which supports the claim (citing specific data)
- Explain the physical **reasoning** that leads you to believe why the claim is true.

Your first draft is due on **Tuesday 11/1/2016.**

➔ It is key that you have a hard copy of your lab report on this day as you will share it with another group to get feedback and revise.

Appendix C

Range of a Projectile Lab – Peer Review

The purpose of this peer review is to support each other in improving our skill at communicating scientific experiments and making an argument to support our analysis of the results.

Read your partner's lab and look for the following pieces,

1) check off if they are present and
2) put the letter of each piece next to where you see it in their report.
3) Then provide them with comments here or on their lab report which will help them communicate more clearly and strengthen their concluding argument.

Introduction

- ◻ A) The objective is clear
- ◻ B) Brief summary of methods
- ◻ C) Connection between the lab and a real world scenario

<u>Comments:</u>

Methods

- ◻ A) All materials needed for data collection are specified
- ◻ B) All steps for data collection are clearly described so you could replicate the experiment <u>exactly</u>.
- ◻ C) There is one clear variable that is changed to determine the effect. Everything else is kept consistent.

<u>Comments:</u>

Results & Analysis

- ◻ A) The data table is organized in a logical way including units.
- ◻ B) The graph are easy to read, axes are properly labeled with units and the trendline chosen accurately represents the trend in the data
- ◻ C) There is an explanation of the relationship between the variables shown in each graph

<u>Comments:</u>

Conclusion – A scientific argument

Claim		Evidence		Reasoning
An explanation or an answer to a research question that…	**is supported by…**	Observations which show trends over time or relationships between variables…	**and is justified by…**	Logical rationale which physically explains the evidence and why its supports the claim

Adapted from Sampson, Grooms, & Walker (2011)

- ◻ C) A clear **claim** is made about the effect of <u>each</u> variable studied. (circle this)
- ◻ E) Reference to **specific evidence** is used to support <u>each</u> claim. (highlight this)
- ◻ **R) Logical** and clear **reasoning** is provided to physically justify why <u>each</u> claim is true. (box this)

<u>Comments:</u>

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